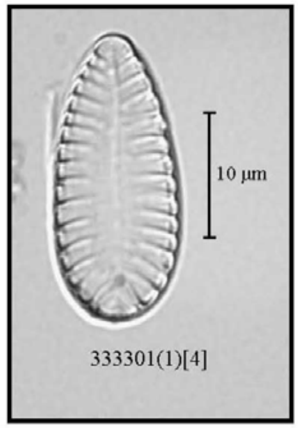
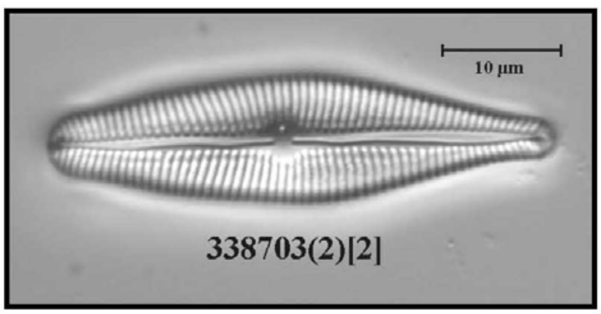
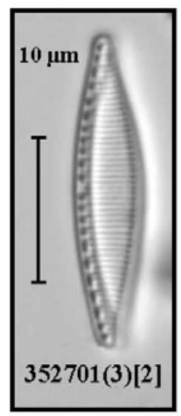
DIATOM BIOCRITERIA FOR MONTANA STREAMS 2005







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September 9, 2005

Cover. Examples of diatom species in mountain streams of western Montana whose populations increase in response to impairment. Clockwise from upper left: *Cocconeis pediculus*, a species that increases in response to general impairment, as well as to sediment, nutrient, and metals impairment; *Surirella minuta*, a species that increases in response to sediment impairment; *Nitzschia fonticola*, a species that increases in response to metals impairment; *Gomphoneis eriense*, a species that increases in response to nutrient impairment.

Diatom Biocriteria for Montana Streams

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September 2005

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Acknowledgements

The authors would like to acknowledge several people who have contributed to this project. First are all the project managers and field technicians responsible for the collection of data used in this analysis. Their on-going commitment to sampling and analysis protocols has provided us comparable data of a known data quality without which, these types of studies would not be possible. We would also like to thank Rosie Sada de Suplee and Michael Suplee with the Montana Department of Environmental Quality whose support, guidance, and collaboration over the years has made this project happen. Thanks also to Tina Laidlaw, US Environmental Protection Agency, Helena, for facilitating the final steps. Finally, we would also like to recognize Sarah Spaulding, US Geological Survey/US Environmental Protection Agency, Denver, for sharing ideas and providing insight into similar efforts at the Federal level.

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Introduction

Periphyton Bioassessment Methods for Montana Streams (Bahls 1993) presents procedural guidelines and numeric biocriteria for using the composition and structure of periphyton communities to assess biological integrity and impairment of aquatic life in Montana streams. This manual was based on the findings of a 1990 Montana reference stream study and follow-up surveys in 1991 (Bahls et al. 1992). Three metrics - sediment index, pollution index, and diversity index - and two sets of biocriteria are provided, one for mountain and foothill streams and one for plains streams. These original metrics have been supplemented by additional metrics adopted by the Montana Department of Environmental Quality (State). These metrics and biocriteria are linked to beneficial use classifications in Montana Surface Water Quality Standards.

While generally accepted, Montana's metrics and biocriteria have not been subject to rigorous data analysis protocols. Advances in biological data analysis and the collection of a large amount of periphyton data since 1993 now offer the opportunity to review existing metrics, test new ones, and refine or develop biocriteria for those metrics. Therefore, the purpose of this study is to use generally accepted statistical protocols and recent periphyton data to develop and test an array of candidate metrics and to revise or establish biocriteria as needed. Biocriteria are evaluated for their ability to address two key questions directly relevant to the State's assessment of naturally flowing streams:

1) Do diatom sample results indicate impairment under 303(d) guidelines?
2) If so, do diatom sample results indicate the cause of impairment?

Criteria developed within this framework are intended to support the State's water quality assessments. Of specific interest to the State is the level of impairment where aquatic life use support is partial or none. Criteria address instances where diatom community response is most likely; that is, impairment due to sediment, nutrients, and/or metals. Diatom community response to other causes is expected to be limited, regardless of the level of impairment, and therefore not addressed.

Methods

Diatom Sample Data

Data used in this study were compiled in the Montana Diatom Database by ***Hannaea***, an analytical diatom laboratory in Helena, Montana. Diatom proportional counts in the database represent approximately 2,000 samples from over 1,500 naturally flowing stream stations throughout Montana. These samples were collected and analyzed following protocols comparable to Montana's bioassessment methods for periphyton (Bahls 1993). Diatoms are identified to species using generally accepted naming conventions and cell counts of each species are recorded in the database.

Reference Stream Samples

Reference stream samples were selected from the Montana Diatom Database for sites that passed screening criteria developed by Suplee et al. (2005). Reference stream sites represent the natural biological, physical and chemical integrity of a region. Stream sites that pass these screening criteria are considered general-purpose reference sites that can be used for both regional-scale analyses and site-specific comparisons. Fifty-six (56) samples were selected from the Montana Diatom Database representing 56 reference streams identified by Suplee et al. (2005). Eight (8) additional samples were selected through screening of 28 potential reference streams that were proposed by the authors but not originally considered by Suplee et al. (2005). A full listing of selected reference stream samples is in **Appendix A**.

Stream Grouping

The intent of stream grouping is to partition streams into groups that are relatively homogeneous with regard to physical, biological, and chemical attributes (Barbour et al. 1999). Grouping helps control the variability within the group such that meaningful evaluation of metric behavior (e.g., reference vs. impaired) can be conducted with minimal influence from extraneous factors. Grouping of reference streams was based on observations of the percentage community similarity index of Whittaker and Fairbanks (1958) (see **Appendix B**) summarized as follows:

1) Most samples representing mountain and foothill ecoregions (15, 16, 17, and 41) exhibit some floristic affinity with one another (similarity index greater than 20);
2) Plains samples (ecoregions 42 and 43) have limited floristic affinity with one another (similarity index less than 20); and,
3) There is generally little or no floristic affinity between mountain and plains samples.

These results generally support the approach of Bahls (1993) wherein metrics were developed separately for streams in mountain and plains ecoregions as defined by the U.S. Environmental Protection Agency (US EPA 2000). By default, these groupings were carried forward.

Impaired Stream Samples

Samples were selected from the Montana Diatom Database representing two groups of impaired streams, defined as follows:

1. Impaired Streams: streams on the Montana 303(d) list as per the 2004 Water Quality Assessment Database at :

   http://nris.state.mt.us/wis/environet/2004Home.html ,

   where aquatic life use support is partial or none and the cause of impairment is sediment, nutrients, and/or metals; and,
2. Other Streams: streams on the Montana 303(d) list where aquatic life use support is full or the cause of impairment is something other than sediment, nutrients, or metals.

Only samples collected since 1995 were considered in order to be representative of recent 303(d) designations. Random sample selection techniques were used to balance sample sizes among impaired, other and reference strata, to represent impairment causes proportionally, and to minimize data dependence within each group. A full listing of selected samples is in **Appendix A**.

Potential Metrics

Table 1 lists diatom metrics considered to be ecologically relevant to Montana streams for the predominant causes of stream impairment to which diatoms are sensitive. Full descriptions of these metrics, and boxplots by stream grouping, can be found in **Appendix C**. Three of these metrics – diversity index, siltation index, and pollution index – were developed and tested in the original Montana methods manual (Bahls 1993). Additional metrics are based largely on diatom autecological studies published since 1993, e.g., van Dam et al. (1994). Not all are necessarily relevant to both mountain and plains streams. For example, percent *Rhopalodiales* is especially important in plains streams where these diatoms are more common and the heavy metals metric is more important in mountain streams. However, all of these metrics are expected to be relevant, ecologically.

In addition to these metrics, an empirical investigation of relative taxa abundance was conducted in order to identify taxa that, as a group, exist in detectable amounts in all populations (reference, other, and impaired) and demonstrate a meaningful, measurable response to sediment, nutrients, and/or metals. This was accomplished by a screening process wherein: 1) standardized taxa counts representing reference, other, and impaired sites were compared to identify those that increase or decrease with impairment, both general and cause-specific; and, 2) standardized taxa counts were filtered to identify those that, as a group, represent about 10 to 15 percent of relative abundance in reference, other, and impaired strata.

The resulting taxa lists include taxa that we are terming “Increasers” and “Decreasers”. Increasers and Decreasers were identified for mountain and plains samples representing general impairment response as well as cause-specific responses.

Metrics were calculated to equal the total relative abundance of taxa on each of these lists (general impairment, sediment impairment, nutrient impairment, metals impairment). Metrics were evaluated individually and in combination.

Table 1. Summary of potential metrics.

Metric	Group[1]	Description
Community Structure		
Shannon's Diversity Index	M, P	Weber (1973)
Diatom Species Richness	M, P	Bahls (1993)
% Native Diatoms	M, P	Adapted from Potapova and Charles (2004)
% Rare Diatoms	M, P	Adapted from Potapova and Charles (2004)
% Cosmopolitan Diatoms	M, P	Abundance of cosmopolitan diatoms
% Dominant Diatom Species	M, P	Abundance of the dominant species
Sediment		
Siltation Index	M, P	Bahls (1993)
% Motile Diatoms	M, P	Abundance of highly and moderately motile diatoms
% Brackish Diatoms	M, P	Abundance of brackish diatoms (plains); abundance of brackish and brackish-fresh diatoms (mountains)
Organic Nutrients		
Pollution Index	M, P	Bahls (1993)
% Nitrogen Heterotrophs	M, P	Abundance of facultative/obligate nitrogen heterotrophs
% Polysaprobous Diatoms	M, P	Abundance of polysaprobous/alpha-mesosaprobous diatoms
% Low DO Diatoms	M, P	Abundance of diatoms with low / very low oxygen demand
Inorganic Nutrients		
% Nitrogen Autotrophs	M, P	Abundance of autotrophic diatoms
% Eutraphentic Diatoms	M, P	Abundance of eutraphentic/hypereutraphentic diatoms
% *Rhopalodiales*	P	Abundance of *Rhopalodiales*
Metals		
Disturbance Index	M	Abundance of *Achnanthidium minutissimum*
% Acidophilous Diatoms	M	Abundance of acidobiontic and acidophlilous diatoms
% Metals Tolerant Diatoms	M	Abundance of metals tolerant diatoms
% Abnormal Cells	M	Abundance of cells exhibiting teratogenic effects

[1] M = Mountain Streams; P = Plains Streams

Metric Evaluation

Discriminant analysis was used to determine impairment status and cause of impairment. Discriminant analysis is used by the State of Maine to predict membership in one of two degradation classes, impaired and not impaired (Davies and Tsomides 2002). Our models considered both general impairment (i.e., impaired due to sediment, nutrients, and/or metals) and cause-specific impairment. For general impairment modeling, the non-impaired class was represented by samples in the reference and other strata; impaired samples represented the impaired stratum defined above. For cause-specific impairment models, the impairment class was represented by impaired samples listed for the specific cause (whether solely or in combination with other causes); all other samples represented non-impaired classes. Metric values derived from biological data are used as independent data in these models.

Discriminant analysis was performed using SYSTAT® Version 11 in both stepwise and complete forms. Model selection was based on progressive criteria: 1) model meaning (i.e., matching expected trends); 2) significance of the model (at least at the 95% confidence level); 3) classification accuracy (at least a 66% overall classification accuracy); and 4) false positive rates (individual classification accuracies greater than 50%). Typically, discriminant analysis is conducted with modeling and validation datasets to independently verify classification accuracies. However, sufficient samples did not exist to permit the splitting of samples into two sets. Therefore, jackknifed classification matrices (i.e., approximations) were used to assess accuracy. For models meeting these criteria, discriminant analysis results were then used calculate the probability of class membership.

Results

Mountain Streams

For mountain streams, none of the metrics listed in **Table 1** could be used to discriminate impairment, neither generally nor by cause. Boxplots presented in **Appendix C** indicate that most metrics matched expected trends. However, none yielded significant models and most had classification accuracies less than 50%. Two observations account for these results. First, and most importantly, there is great variability of metric values within each stratum. Consequently, whereas central tendencies match trends, this variability decreases the power to detect the difference. Second, and related to variability, many of these metrics exhibit a gradual response to environmental stress, as is expected. This contributes to variability and thereby masks the ability to discriminate by impairment class. Therefore, while not discriminating, many of these metrics are still usefulin the hands of an experienced ecologist for judging the levels and causes of impairment.

The best models for discriminating impairment among mountain streams were based on percent abundance of Increasers. Three lists were developed through the screening criteria outlined above (see **Table 2**). These lists are cause-specific and represent taxa that, as groups, discriminate between sites impaired for the specified cause (whether solely or in combination with other causes) and all other sites. Metrics calculated from these lists were used in discriminant analysis to generate classification models. A fourth model, based on a metric representing the combination of these lists, was developed to use these taxa as a group to generally discriminate between non-impaired sites and impaired sites. No model meeting our criteria could be developed for Decreasers among mountain streams. Models developed are as follows:

(1) $Score_{MountainsSediment} = (\%\ Increasers_{MountainsSediment} – 17.000) / 14.579$

where:

if $Score_{MountainsSediment} >= 0.260$, then classify as Sediment Impaired; or,

if $Score_{MountainsSediment} < 0.260$, then classify as Not Sediment Impaired.

(2) $Score_{MountainsNutrients} = (\%\ Increasers_{MountainsNutrients} – 17.234) / 15.613$

where:

if $Score_{MountainsNutrients} >= 0.614$, then classify as Nutrient Impaired; or,

if $Score_{MountainsNutrients} < 0.614$, then classify as Not Nutrient Impaired.

(3) $Score_{MountainsMetals} = (\%\ Increasers_{MountainsMetals} – 18.896) / 14.976$

where:

if $Score_{MountainsMetals} >= 0.619$, then classify as Metals Impaired; or,

if $Score_{MountainsMetals} < 0.619$, then classify as Not Metals Impaired.

(4) $Score_{MountainsGeneral} = (\%\ Increasers_{MountainsGeneral} - 21.478)\ /\ 19.522$

where:

if $Score_{MountainsGeneral} >= 0.170$, then classify as Impaired; or,

if $Score_{MountainsGeneral} < 0.170$, then classify as Not Impaired.

Each model is considered meaningful in that taxa on these lists are observed to increase – individually and as a group – in response to observed impairment over a geographically broad dataset. Furthermore, a review of independent autecological data for these taxa supports their listing as increasers in response to disturbance (van Dam et al. 1994). Each model was significant (p<0.0001) and jackknifed total classification accuracies were 73%, 84%, 80%, and 69%, respectively. For most impairment classes, individual classification accuracy rates exceeded 60%; in all instances, individual classification accuracy rates were greater than 50%.

Table 2. Increaser taxa screened for mountain streams.

Sediment Impairment: Equation (1)	Nutrient Impairment: Equation (2)	Metals Impairment: Equation (3)
Amphora pediculus	*Cocconeis pediculus**	*Caloneis bacillum*
*Cocconeis pediculus**	*Cocconeis placentula*	*Cocconeis pediculus**
*Diatoma vulgaris**	*Cymbella excisiformis*	*Cymbella excisa*
*Encyonopsis subminuta**	*Diatoma moniliformis*	*Diatoma vulgaris**
*Epithemia sorex**	*Encyonopsis microcephala*	*Encyonema minutum*
Gomphonema olivaceum	*Encyonopsis subminuta**	*Encyonopsis subminuta**
Navicula capitatoradiata	*Epithemia sorex**	*Eolimna minima*
Navicula gregaria	*Gomphoneis eriense*	*Epithemia sorex**
*Navicula lanceolata**	*Gomphoneis minuta**	*Gomphoneis minuta**
Navicula reichardtiana	*Gomphonema angustatum*	*Gomphonema pumilum*
Navicula tripunctata	*Gomphonema angustum*	*Nitzschia fonticola*
Nitzschia archibaldii	*Gomphonema kobayasii*	*Nitzschia hantzschiana**
*Nitzschia hantzschiana**	*Gomphonema parvulum*	*Pseudostaurosira brevistriata**
Nitzschia inconspicua	*Navicula lanceolata**	*Rhoicosphenia abbreviata**
Nitzschia palea	*Navicula menisculus*	*Rhopalodia gibba*
Nitzschia sociabilis	*Nitzschia hantzschiana**	*Staurosira construens*
*Pseudostaurosira brevistriata**	*Nitzschia paleacea*	*Staurosirella pinnata*
*Rhoicosphenia abbreviata**	*Pseudostaurosira brevistriata**	*Synedra acus*
Stephanocyclus meneghiniana	*Rhoicosphenia abbreviata**	*Synedra rumpens*
Surirella minuta		
Synedra mazamaensis		
Synedra ulna		

* = Indicates taxa common among cause-specific lists.

Scores calculated from Equations (1) through (4) are distributed normally and centered about the criteria breaks. Therefore, the probability of class membership can be determined via tables of normal distributions. For instance, if the percent relative abundance of sediment Increasers is 35 percent, using Equation (1) yields a calculated score value of 1.235. By using a normal probability table, standardizing this score about the criteria break of 0.260, the probability that the sample represents a stream impaired by sediment is about 84%. **Table 3** presents classification probabilities for discrete values of percent relative abundance, as a group, of Increasers represented by the taxa lists in **Table 2.**

Table 3. Probability of impairment class membership of mountain streams based on percent relative abundance of Increasers (see Table 2).

Percent Relative Abundance	Probability of Impairment			
	Sediment Impairment: Equation (1)	Nutrient Impairment: Equation (2)	Metals Impairment: Equation (3)	General Impairment: Equation (4)
5	13.94%	8.11%	6.09%	15.53%
10	22.96%	14.07%	11.26%	22.42%
15	34.56%	22.45%	18.97%	30.79%
20	47.84%	33.11%	29.28%	40.30%
25	61.36%	45.36%	41.63%	50.42%
30	73.62%	58.07%	54.87%	60.51%
35	83.51%	69.98%	67.59%	69.94%
40	90.62%	80.07%	78.53%	78.19%
45	95.16%	87.79%	86.95%	84.96%
50	97.74%	93.12%	92.76%	90.17%
55	99.05%	96.45%	96.34%	93.91%
60	99.64%	98.32%	98.32%	96.43%
65	99.88%	99.28%	99.30%	98.03%
70	99.96%	99.72%	99.74%	98.97%
75	99.99%	99.90%	99.91%	99.49%

Plains Streams

For plains streams, none of the metrics listed in **Table 1** could be used to discriminate impairment, neither generally nor by cause. Boxplots presented in **Appendix C** indicate that most community metrics and nutrient-specific metrics matched expected trends; all the sediment-specific metrics did not match expected trends. None yielded significant models and most had classification accuracies less than 50%. As with mountain samples, plains samples exhibit great variability thereby masking the ability to discriminate by impairment class. But again, while not discriminating, some of these metrics are still useful in the hands of an experienced ecologist, for judging the levels and nutrient-related causes of impairment.

The best models for discriminating impairment among plains streams were based on percent abundance of Increasers and Decreasers. Three lists were developed through the screening criteria outlined above (see **Table 4**). The first two lists are cause-specific and represent taxa that, as groups, discriminate between sites impaired for the specified cause (whether solely or in combination with other causes) and all other sites. Used individually, these lists yield significant models with acceptable overall classification accuracies. However, these models had high false positive rates, tending to classify nutrient-impaired sites as sediment-impaired and vice versa. Because of this they were determined to not have discriminating ability and were therefore combined for general impairment modeling. The third list represents taxa that decrease to detectable amounts from impaired to non-impaired strata as environmental stress decreases, irrespective of cause. Models developed follow:

(5) $Score_{PlainsGeneral} = (\%Increasers_{PlainsGeneral} – 27.181) / 13.950$

where:

if $Score_{PlainsGeneral} >= 0.445$, then classify as Impaired; or,

if $Score_{PlainsGeneral} < 0.445$, then classify as Not Impaired.

(6) $Score_{PlainsGeneral} = (\%Decreasers_{PlainsGeneral} – 23.031) / 15.691$

where:

if $Score_{PlainsGeneral} >= -0.228$, then classify as Not Impaired; or,

if $Score_{PlainsGeneral} < -0.228$, then classify as Impaired.

Table 4. Increaser and Decreaser taxa screened for plains streams.

Sediment Increasers: Equation (1)	Nutrient Increasers: Equation (1)	General Decreasers: Equation (2)
Achnanthidium minutissimum	*Cocconeis pediculus*	*Amphipleura pellucida*
*Cocconeis pediculus**	*Cymbella affinis**	*Amphora copulata*
*Cymbella affinis**	*Diatoma moniliformis**	*Biremis circumtexta*
*Diatoma moniliformis**	*Encyonema minutum**	*Cocconeis placentula*
*Encyonema minutum**	*Epithemia sorex**	*Cymbella pusilla*
Encyonema silesiacum	*Gomphonema olivaceum**	*Entomoneis paludosa*
Encyonopsis microcephala	*Mastogloia smithii*	*Hippodonta capitata*
*Epithemia sorex**	*Navicula cincta v. rostrata**	*Navicula canalis*
*Gomphonema olivaceum**	*Navicula duerrenbergiana**	*Navicula capitatoradiata*
*Navicula cincta v. rostrata**	*Navicula recens*	*Navicula gregaria*
Navicula cryptotenella	*Navicula reichardtiana*	*Navicula salinarum*
*Navicula duerrenbergiana**	*Nitzschia acicularis**	*Navicula veneta*
Navicula erifuga	*Nitzschia amphibia*	*Nitzschia agnita*
Navicula tripunctata	*Nitzschia archibaldii**	*Nitzschia frustulum*
*Nitzschia acicularis**	*Nitzschia dissipata**	*Nitzschia incognita*
*Nitzschia archibaldii**	*Nitzschia filiformis*	*Nitzschia liebetruthii*
*Nitzschia dissipata**	*Nitzschia leistikowii**	*Nitzschia linearis*
*Nitzschia leistikowii**	*Rhoicosphenia abbreviata**	*Nitzschia microcephala*
Pseudostaurosira brevistriata	*Staurosira construens**	*Nitzschia perminuta*
*Rhoicosphenia abbreviata**	*Synedra ulna**	*Nitzschia supralitorea*
*Staurosira construens**		*Nitzschia valdestriata*
*Synedra ulna**		*Rhopalodia gibba*
		Stephanocyclus meneghiniana
		Tabularia fasciculata
		Tryblionella apiculata

* = Indicates taxa common among cause-specific lists.

Most, but not all, Increasers on this list are recognized indicators of stress due to sediment and/or nutrients. Few, if any, Decreasers on this list are widely recognized as intolerant to environmental stress, whereas many are known to be tolerant of elevated salinity, organic nutrient loading, and other perturbations. Their occurrence among impaired samples at detectable levels (10 to 15 percent relative abundance) is evidence of this tolerance; they are present in significant numbers at both impaired and reference sites. But why they occur at higher levels among reference and other samples is unknown. Even the best sites in the plains support tolerant taxa and the range of impairment for sediment and nutrients in the plains is arguably less than in the mountains. Therefore, the Decreaser list is plausible, though not fully understood.

These models were significant ($p<0.0001$) and had an overall classification accuracy of

88% and 72%, respectively. Individual classification accuracies were all over 66%. Scores calculated from Equations (5) and (6) are distributed normally and centered about the criteria breaks. Therefore, the probability of class membership can be determined via tables of normal distributions. **Table 5** presents classification probabilities for discrete values of percent relative abundance. In this table, note probabilities associated with Increasers and Decreasers are inversely related to one another, as expected.

Table 5. Probability of impairment class membership of plains streams based on percent relative abundance of Increasers and Decreasers.

Percent Relative Abundance	Probability of Impairment	
	Sediment and Nutrient Increasers: Equation (5)	General Decreasers: Equation (6)
5	2.09%	82.15%
10	4.68%	59.95%
15	9.37%	46.38%
20	16.86%	33.22%
25	27.38%	21.87%
30	40.40%	13.14%
35	54.60%	7.18%
40	68.22%	3.55%
45	79.74%	1.58%
50	88.31%	0.64%
55	93.93%	0.23%
60	97.18%	0.07%
65	98.83%	0.02%
70	99.57%	0.01%
75	99.86%	0.00%

Interpretation

Mountain Streams

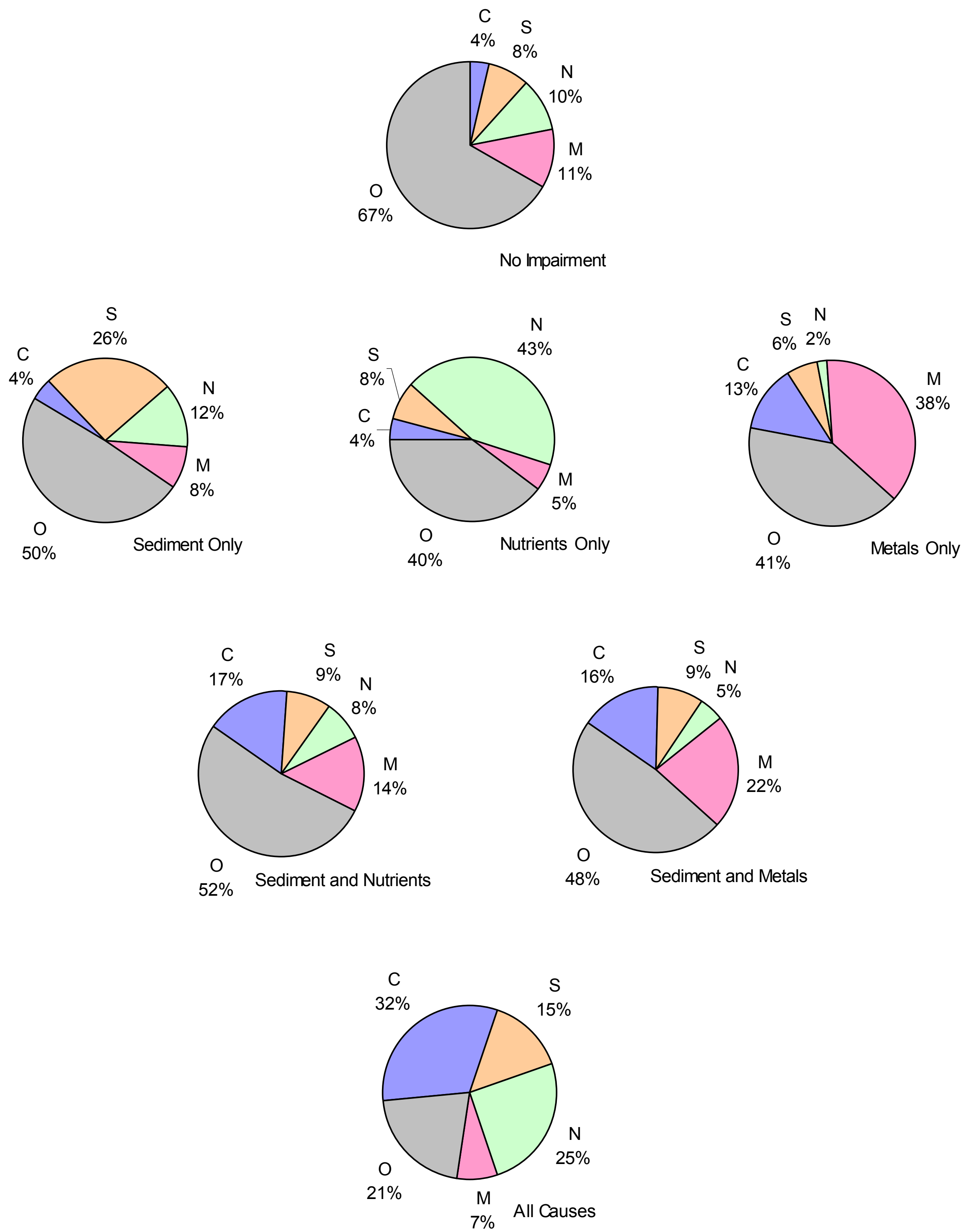
Empirical evaluation of taxa relative abundance provides insight into the dynamics of diatom communities under stress and, in doing so, supports interpretation how well these models perform. For mountain samples, we calculated the relative abundance of taxa in the following groups derived from the cause-specific lists in **Table 2**: taxa common to the sediment, nutrients, and/or metals lists (C); taxa unique to the sediment list (S); Taxa unique to the nutrients list (N); taxa unique to the metals list (M); and, taxa not occurring on any list (O). **Figure 1** presents pie charts of these relative abundances for samples representing non-impaired streams (reference and other) and samples impaired for single and combined causes for impairment. Collectively, they portray the dynamics of taxa assemblages across the impairment continuum.

Three key trends are evident. First is the manner in which taxa unique to a cause for impairment (groups S, N, and M) respond to environmental stress. These taxa are present at detectable levels in the absence of impairment. Their response is greatest – a significant increase – when there is only one cause of impairment. This increase is greatest for nutrients and metals; sediment response is smaller, but just as powerful a discriminator. Taxa unique to these cause-specific lists may therefore be considered as ecological **specialists** that are tolerant of that cause. Among samples representing two or three causes, relative abundance of each cause-specific group then decreases and the size of the common group and other group increases.

Second is the manner in which taxa common to causes (C) respond to environmental stress. These taxa are also present at detectable levels in the absence of impairment. With the exception of metals impairment, however, they show little response where there is only one cause of impairment. Among samples representing two causes of impairment, there is then an order of magnitude increase in relative abundance of these taxa. Where all three causes of impairment are present, relative abundance of these taxa doubles, yet again. Given this trend, taxa common to the cause-specific lists in **Table 2** may therefore be considered ecological **generalists** and most tolerant to these causes in combination.

Third is the manner in which all other taxa not listed for any cause (O) respond to environmental stress. Among reference and other impaired samples, these taxa account for about two-thirds of the total relative abundance. Among samples with one or two causes of impairment, this proportion reduces to about 40 to 50 percent. In

Figure 1. Dynamics of relative abundance for different combinations of observed impairment among mountain samples for the following taxa groups: C – Common; S – Sediment; N – Nutrients; M – Metals; and, O - Other.



samples representing all causes of Impairment, only about 20 percent are these other taxa and eighty percent of the diatoms represent cause-specific taxa. Given this trend, taxa not on any cause-specific list may be considered either **sensitive** or **indifferent** to environmental stressors or **incidental** (introduced from other habitats) and occurring at relatively low abundance in all strata. About 430 of these taxa were observed in mountain samples. Most have a relatively low frequency of occurrence region-wide. As a group, however, they are too diverse to comprise a meaningful metric.

What does this mean? From an empirical standpoint, diatom populations are being observed to change in meaningful ways in response to environmental stress. Depending on the stressor, this change occurs in differing amounts, but all changes are equally significant statistically. Furthermore, throughout these changes, diversity remains more or less unchanged. Essentially, we are observing taxa “trading places” in the diatom assemblage and these changes are driven by environmental stress. In short, populations of some taxa increase and populations of other taxa decrease depending on the number and combination of causes. An understanding of the foregoing is critical for interpreting the models presented above.

Table 6 summarizes classification accuracies by model for samples representing impairment combinations presented in **Figure 1**. In most cases, Equations (1) through (4) work consistently in discriminating impairment. Classification accuracy is below 50% in only three instances, all where two causes of impairment combine. Among samples impaired by sediment and nutrients or sediment and metals, cause-specific models do not reflect 303(d) determinations. This is visually evident in **Figure 1** where the distributions are virtually indistinguishable between these two combinations. Equation (4), however, can discriminate general impairment in these instances; hence, its inclusion. Otherwise, these models represent the dynamics portrayed in **Figure 1**.

Table 6. Classification accuracies of mountain samples calculated by Equations (1) through (4).

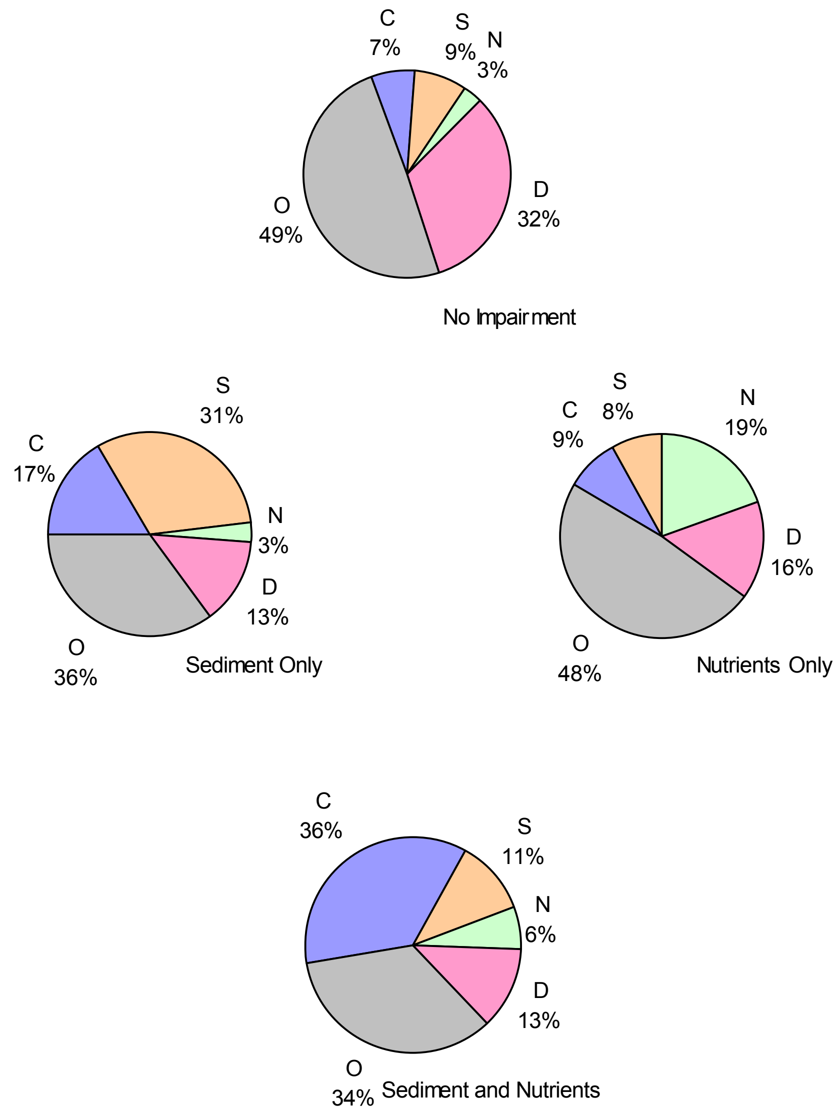
Impairment Cause	Classification Accuracy by Model			
	Sediment Impairment: Equation (1)	Nutrients Impairment: Equation (2)	Metals Impairment: Equation (3)	General Impairment: Equation (4)
XXX	78%	85%	85%	68%
SXX	79%	86%	100%	79%
XNX	100%	67%	100%	67%
XXM	75%	75%	100%	50%
SNX	33%	33%	50%	50%
SXM	38%	75%	63%	63%
SNM	100%	100%	75%	100%

Plains Streams

For plains samples, we calculated the relative abundance of taxa in the following groups derived from the cause-specific lists in **Table 4**: taxa common to the sediment and nutrients lists (C); taxa unique to the sediment list (S); taxa unique to the nutrients list (N); taxa occurring on the Decreaser list (D); and, taxa not occurring on any list (O). **Figure 2** presents pie charts of these relative abundances for samples representing non-impaired streams (reference and other) and samples impaired for single and combined causes for impairment. Collectively, these charts portray the dynamics of taxa assemblages across the impairment continuum.

Three key trends are evident. First is the manner in which taxa unique to a cause for impairment (groups S and N) respond to environmental stress. As in the mountains, these taxa are present at detectable levels in the absence of impairment. Their response is greatest – a significant increase – when there is only one cause of impairment. Visually, these responses are notable, given that only a few taxa are represented on these lists; but neither is a significant discriminator. This lack of significance is due mostly to too few samples available for impaired sites. Among samples representing the combination of sediment and nutrients impairment, relative abundance of each cause-specific group decreases and the relative size of the common group increases.

Figure 2. Dynamics of relative abundance for different combinations of observed impairment among plains samples for the following taxa groups: C – Common Increasers; S – Sediment Increasers; N – Nutrients Increasers; D - Decreasers; and, O - Other.



Second is the manner in which taxa common to both causes (C) respond to environmental stress. These taxa are also present at detectable levels in the absence of impairment. Taxa common to lists of both sediment and nutrient Increasers show some increase where there is only one cause of impairment. However, this group increases the most when impairment by sediment and nutrients occurs in combination. While these same trends were statistically significant in the mountains, they are not significant among plains streams. Consequently, one can consider all three of these groups – C, S, and N – as **generalists** that are tolerant of both causes, singly or in combination. Qualitatively, these trends should be noted for further investigation.

Third is the manner in which Decreasers respond to environmental stress. Among reference and other impaired samples, these taxa account for about one-third of the total relative abundance. Twenty-five taxa are on this list, occurring in differing combinations in these samples. Among samples with one or two causes of impairment, this proportion reduces to about 15 percent; but they don't drop out completely. Given the significance of this trend, taxa on the Decreaser list appear to be **sensitive** to sediment and nutrients, but paradoxically **tolerant** even at the highest levels of impairment. Several of these Decreasers are tolerant of elevated dissolved solids. Salinity is a factor that we did not address in our analysis and it is possible that the selected reference and other sites have higher levels of dissolved solids, on average, than sites impaired by sediment and nutrients. This could be tested by examining chemistry data for these sites.

All other taxa in these pie charts (O) should be considered **indifferent** to environmental stressors or **incidental** (introduced from other habitats) and occurring at relatively low abundance in all strata. About 350 taxa comprise this group.

From an empirical standpoint, diatom populations are being observed to change in meaningful ways in response to environmental stress. However, unlike the mountains, they do not do so in a manner helping us interpret the cause of impairment. **Table 7** summarizes classification accuracies by model for samples representing impairment combinations presented in **Figure 2**. For both Equations (5) and (6), classification accuracy is consistently greater than 66% in all instances. Equation (5) is notably stronger in its ability to discriminate non-impaired sites. Among impaired samples, our sample size was too low to ascribe any meaningful difference among classification accuracies; they are practically equivalent. Used as discriminators of general impairment, both models represent the general dynamics portrayed in **Figure 2**.

Table 7. Classification accuracies of plains samples calculated by Equations (5) and (6).

Impairment Cause	Classification Accuracy by Model	
	Sediment and Nutrient Increasers: Equation (5)	General Decreasers: Equation (6)
XX	89%	68%
SX	100%	71%
XN	75%	100%
SN	89%	78%

Discussion

The primary objective of empirical investigation of taxa relative abundance was to identify groups of taxa that existed in detectable numbers in all populations (reference, other, and impaired) and demonstrated a meaningful, measurable response to observed stress. Resulting models can be used to determine the **probability of membership** in either the impaired or non-impaired classification. This probability is directly related to the samples used in modeling. Samples representing reference and impaired conditions virtually exhaust available diatom data and they do exceed power requirements (β=.80) generally considered adequate for these metrics. Nevertheless, it is up to the investigator using these models to review the sample lists to determine the representativeness of these models for their particular investigation.

Given the foregoing, how does this compare to Periphyton Bioassessment Methods for Montana Streams (Bahls 1993)? Metrics used in Bahls (1993), all of which are included in **Table 1**, are presumptive. They expect a certain response to environmental stress based on investigations conducted world-wide and the universality of diatom autecological data. Most of the metrics in **Table 1** are driven by lists of taxa and their observed ecological attributes. Models presented in Equations (1) through (6) are also driven by taxa lists (**Table 2** and **Table 4**). These lists are generally shorter than those used in Bahls (1993), but they include many of the same taxa. The difference is that the lists presented here use sample data directly relevant to Montana streams to tell us which taxa are **most responsive** to sediment, nutrients, and/or metals impairment.

Because the Periphyton Bioassessment Methods for Montana Streams (Bahls 1993) is based on **Table 1** metrics, we would not expect them to perform well in classifying samples. And because criteria breaks are based on presumptive thresholds, they do not reflect the empirical distribution of metric values demonstrated by these samples. This is another reason why they should not be expected to perform well. **Table 8** presents classification accuracies for mountain and plains samples evaluated using the current State biocriteria in **Appendix D**. As expected, these biocriteria would not pass our standards for model selection based on classification accuracies. In that regard, the new models are better at discriminating impairment and, where possible, cause of impairment. To be fair, however, validation via an independent data set would be the only way to state whether Equations (1) through (6) represent an improvement.

Table 8. Classification accuracies of mountain samples and plains samples evaluated using current State criteria in Appendix D.

Impairment Cause	Mountains			Plains
	Sediment Impairment	Nutrients Impairment	Metals Impairment	General Impairment
XXX	88%	96%	85%	74%
SXX	29%	100%	93%	29%
XNX	67%	33%	100%	50%
XXM	100%	100%	25%	N/A
SNX	0%	0%	83%	22%
SXM	0%	100%	25%	N/A
SNM	0%	0%	0%	N/A

Therefore, Equations (1) through (6) are offered as an alternative to the Periphyton Bioassessment Methods for Montana Streams (Bahls 1993) as revised and expanded in **Appendix D**. Independent validation over the range of stream conditions in Montana would be critical to stating their reliability. As part of this validation, it is recommended that ancillary data expressing the level of impairment (i.e., chemical and physical data) be collected such that within and between strata variability can be addressed, further improving their discriminatory power. Nonetheless, these models are founded in much the same ecological basis as those in **Appendix D**. They simply apply a different set of observations that are directly relevant to Montana streams.

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Appendix A: Reference and Impaired Sample Listing, Mountain Streams

Strata	Sample	Date	HUC	Segment ID	Segment Name	ALU	Cause(s)
Reference	13003	8/21/1990	10070005	WESTFORK_118_C	WEST FORK STILLWATER CUS001 ABOVE ADIT	F	XXX
Reference	34301	7/28/1977	17010206	MooseCre_056_C	Moose Creek	F	XXX
Reference	48601	7/14/1978	10020008	SFSpanis_407_C	South Fork Spanish Creek, Spanish Peaks Wilderness	F	XXX
Reference	75213	8/10/1992	17010203	Blackfoo_006_C	Blackfoot River	F	XXX
Reference	76102	7/25/1996	10010001	BellyRiv_408_C	Belly River at 3-mile Campsite (Glacier NP)	F	XXX
Reference	77901	2/11/1981	10070001	GardnerR_404_C	Gardner River at mouth, Yellowstone National Park	F	XXX
Reference	101402	8/5/1992	10070006	WFRockCr_405_C	West Fork Rock Creek above Silver Run	F	XXX
Reference	103201	7/16/1988	10030201	CrazyCre_409_C	Crazy Creek below Mount Patrick Pass, Bob Marshall	F	XXX
Reference	105107	7/8/2001	10020004	SeymourC_076_C	Seymour Creek	F	XXX
Reference	105502	6/17/2001	10030205	waldrn99_270_C	waldrn	F	XXX
Reference	105703	8/6/1993	10030104	SUNRIVER_116_C	SUN RIVER S. FORK BELOW STRAIGHT CREEK	F	XXX
Reference	105903	7/22/1993	10070002	ARMSTRON_109_W	ARMSTRONG SPRING CREEK AT O'HAIR RANCH	F	XXX
Reference	106001	7/31/1990	10020007	ODellCk9_236_C	O'Dell Ck	F	XXX
Reference	106201	8/22/1990	10070006	LAKEFORK_113_C	LAKE FORK OF ROCK CREEK	F	XXX
Reference	106301	9/13/1990	10070002	Fourmile_112_C	Fourmile Creek	F	XXX
Reference	106501	7/26/1990	10070002	PineCk99_238_C	Pine Ck	F	XXX
Reference	106602	7/29/2001	10030103	CalfCree_017_C	Calf Creek	F	XXX
Reference	106701	7/10/1990	10080010	CROOKEDC_111_C	CROOKED CREEK ABOVE TILLETT RANCH	F	XXX
Reference	106901	7/26/1990	10070002	BigCk999_180_C	Big Ck	F	XXX
Reference	140212	7/28/2003	17010202	RockCree_071_C	Rock Creek near Clinton	F	XXX
Reference	149701	9/13/1994	10020007	MadisonR_406_C	Madison River near West Yellowstone in Yellowstone National Park	F	XXX
Reference	201501	8/21/2000	10020008	Gallatin_040_C	Gallatin River	F	XXX
Reference	206801	7/26/2000	10020004	LittleLa_049_C	Little Lake Creek	F	XXX
Reference	224902	9/12/2002	10020008	SCottonw_073_C	S. Cottonwood Creek	F	XXX
Reference	235001	7/23/2001	17010204	SilverCr_078_C	Silver Creek (Site 2)	F	XXX
Reference	235101	7/24/2001	17010204	DeerCree_023_C	Deer Creek	F	XXX
Reference	237301	8/14/2001	10070006	SeeleyCr_075_C	Seeley Creek	F	XXX
Reference	237401	8/15/2001	10070006	WyomingC_107_C	Wyoming Creek	F	XXX
Reference	237501	9/1/2001	10020001	ElkSprin_037_C	Elk Springs Creek	F	XXX
Reference	251901	7/25/2002	10030205	Blacklea_008_W	Blackleaf Creek (Site 2)	F	XXX
Reference	261201	9/5/2002	17010211	GoatCree_043_C	Goat Creek (Site 2)	F	XXX
Reference	263301	9/24/2002	10020003	MillUp99_053_C	Mill (Up)	F	XXX
Reference	263701	9/25/2002	10020003	NFKGreen_058_C	N. FK. Greenhorn Creek	F	XXX
Reference	267101	8/13/2002	17010209	SOUTHFKF_115_C	SOUTH FK FLATHEAD R. ABV HUNGRY HORSE RES	F	XXX
Reference	297901	7/16/2003	10020004	LaMarche_048_C	LaMarche Creek	F	XXX
Reference	338901	8/19/2003	17010213	EFkBullR_025_C	E. Fk. Bull River (Down)	F	XXX
Reference	339001	8/28/2003	10070005	EastRose_033_C	East Rosebud Creek	F	XXX
Reference	339101	8/23/2003	10030205	nfktet99_234_C	nfktet	F	XXX
Reference	339601	7/31/2003	17010205	RoaringL_068_C	Roaring Lion Creek	F	XXX

Appendix A: Reference and Impaired Sample Listing, Mountain Streams

Strata	Sample	Date	HUC	Segment ID	Segment Name	ALU	Cause(s)
Other	50906	8/13/2002	17010207	MT76I001_010	MIDDLE FORK FLATHEAD RIVER, Headwaters to mouth	F	XXX
Other	95302	7/20/1998	10030205	MT41O001_030	TETON RIVER from North and South Forks to Deep Cr.	P	XXX
Other	140210	8/23/2001	17010202	MT76E002_010	ROCK CREEK mainstem from headwaters to mouth (Clark Fork)	F	XXX
Other	149810	8/14/2002	10020007	MT41F001_030	MADISON RIVER from Hebgen Dam to Quake Lake	F	XXX
Other	156901	7/20/1995	10050006	MT40G001_020	SAGE CREEK, Headwaters to Laird Cr	F	XXX
Other	182901	10/3/1998	10030104	MT41K002_030	FORD CREEK, headwaters to 2 miles above the mouth	F	XXX
Other	183401	9/14/1998	10030103	MT41J002_012	SMITH RIVER NORTH FORK from headwaters to Lake Sutherlin	F	XXX
Other	198901	8/1/2000	10070003	MT43A002_031	COTTONW OOD CREEK, Little Cottonwood Cr to the mouth (Shields R)	P	XXX
Other	199701	8/17/2000	10070002	MT43B004_061	TOM MINER CREEKTepee Cr. to the mouth (Yellowstone R)	P	XXX
Other	206501	7/21/2000	10020004	MT41D004_140	MINER CREEK from headwaters to mouth (Big Hole R)	F	XXX
Other	208301	7/11/2000	10030102	MT41Q003_020	MIDDLE FORK OF THE DEARBORN RIVER, Headwaters to the mouth (Dearborn R)	F	XXX
Other	219501	8/21/2001	10040103	MT41S004_051	COTTONW OOD CREEK from headwaters to county road bridge in T14N R18E Sec18.	F	XXX
Other	220101	6/29/2001	10020004	MT41D004_040	SCHULTZ CREEK from headwaters to mouth (Johnson Cr)	F	XXX
Other	225502	6/21/2001	10030205	MT41O002_041	BLACKLEAF CREEK from headwaters to Cow Cr.	F	XXX
Other	235501	8/2/2001	17010204	MT76M003_060	WARD CREEK from headwaters to the mouth (ST. Regis R)	F	XXX
Other	236201	8/8/2001	17010205	MT76H002_010	EAST FORK BITTERROOT RIVER, Anaconda-Pintlar W ilderness Boundary to the mouth (Bitter	F	XXX
Other	255101	8/6/2002	17010201	MT76G002_132	PETERSON CREEK from Jack Cr. to the mouth (Clark Fork R)	N	XXX
Other	256301	9/20/2002	10040203	MT40B001_050	SOUTH FOOK FLATW ILLOW CREEK, Headwaters to confluence with North Fork	F	XXX
Other	257301	9/12/2002	10020008	MT41H002_031	SOUTH COTTONW OOD CREEK, Middle Cr Assoc Ditch diversion to the mouth (Gallatin R)	P	XXX
Other	261501	9/4/2002	17010211	MT76K003_040	ELK CREEK from road crossing in T20N R17W Sec 16 to mouth (Swan R)	P	XXX
Other	261801	9/5/2002	17010211	MT76K003_061	PIPER CREEK from headwaters to Moore Cr.	F	XXX
Other	263101	9/18/2002	10020003	MT41C003_140	HAWKEYE CREEK headwaters to mouth (MF Ruby R)	F	XXX
Other	265301	8/20/2002	10020007	MT41F004_030	BEAVER CREEK from headwaters to the mouth (Quake Lake)	F	XXX
Other	266601	9/11/2002	10030101	MT41I006_179	GRANITE CREEK from headwaters to mouth (Austin Cr - Greenhorn Cr - Sevenmile Cr)	F	XXX
Other	267201	8/29/2002	10020008	MT41H001_010	GALLATIN RIVER from Spanish Cr to the mouth (Missouri R)	P	XXX
Other	287701	6/23/2003	10070003	MT43A002_052	ROCK CREEK from headwaters to Little Rock Cr.	F	XXX
Other	290001	8/15/2003	10070002	MT43B004_132	BOULDER RIVER from NF boundary to 5 mi above the mouth (Yellowstone R)	F	XXX
Other	292301	8/18/2003	10020003	MT41C003_070	NORTH FK GREENHORN CR from headwaters to confluence with South Fk	F	XXX
Other	295001	6/10/2003	10040101	MT41T002_040	EAGLE CREEK from headwaters to Dog Cr	F	XXX
Other	304801	7/24/2003	17010204	MT76M004_031	McCORMICK CREEK from Little McCormick Cr. to the mouth (Ninemile Cr)	P	XXX
Other	308001	8/12/2003	17010101	MT76D004_040	SWAMP CREEK from the headwaters to the mouth at Fortine Cr	P	XXX
Other	327701	10/21/2003	17010210	MT76P003_030	EAST FORK SW IFT CREEK from headwaters to mouth (Swift Cr)	P	XXX
Other	331601	9/26/2003	17010203	MT76F003_060	BLACK BEAR CREEK T12N R12W Sec 22SE	N	XXX
Other	332301	9/28/2003	17010203	MT76F003_071	WASHINGTON CREEK from headwaters to Cow Gulch	N	XXX
Impaired	8206	8/19/2003	10070002	MT43B004_131	BOULDER RIVER from the mouth (Yellowstone R) five miles upstream	P	XXM
Impaired	12302	8/21/2001	17010201	MT76G004_010	LITTLE BLACKFOOT RIVER from Dog Cr to the mouth (Clark Fork R)	P	SNM
Impaired	27828	8/22/2001	17010205	MT76H001_030	BITTERROOT RIVER from Eightmile Cr to the mouth (Clark Fork R)	P	SNM
Impaired	32808	8/22/2002	17010102	MT76C001_010	FISHER RIVER from the Silver Butte / Pleasant Valley junction to the mouth (Kootenai R)	P	XXM
Impaired	35203	6/27/2002	10030101	MT41I006_050	PRICKLY PEAR CREEK from Spring Cr to Lump Gulch	N	SXM

Appendix A: Reference and Impaired Sample Listing, Mountain Streams

Strata	Sample	Date	HUC	Segment ID	Segment Name	ALU	Cause(s)
Impaired	39404	7/12/2001	10020005	MT41G001_010	JEFFERSON RIVER from headwaters to mouth (Missouri R)	N	SXM
Impaired	75224	9/11/2002	17010203	MT76F001_033	BLACKFOOT RIVER from Belmont Cr. to mouth (Clark Fork)	P	XNX
Impaired	149909	8/8/2001	10020007	MT41F001_010	MADISON RIVER from Ennis Dam to the mouth (Missouri R)	P	SXM
Impaired	156701	7/19/1995	10030203	MT41P002_050	CORRAL CREEK, Headwaters to mouth at Government-Cottonwood Crs	P	XNX
Impaired	168902	7/30/2001	10030101	MT41I006_160	SEVENMILE CREEK from headwaters to the mouth (Tenmile Cr)	P	SNM
Impaired	183301	10/3/1998	10030104	MT41K002_020	FORD CREEK, from mouth 2 miles upstream (Smith Cr-Elk Cr-Sun R)	P	SXX
Impaired	184001	6/18/1999	10030103	MT41J001_020	SMITH RIVER from Hound Cr. to the mouth (Missouri R)	P	SNX
Impaired	184201	8/18/1999	10020007	MT41F004_050	JACK CREEK from headwaters to the mouth (Madison R)	P	SXX
Impaired	184401	8/16/1999	10020007	MT41F004_060	NORTH MEADOW CREEK from headwaters to the mouth (Enis Lake)	F	SNX
Impaired	198301	7/21/2000	10070005	MT43C001_010	STILLWATER RIVER from headwaters to Flood Cr	P	SXM
Impaired	198401	8/1/2000	10020004	MT41D003_070	CALIFORNIA CREEK from headwaters to mouth (French Cr-Deep Cr)	N	SXM
Impaired	200201	8/8/2000	10040103	MT41S004_040	CASINO CREEK, Headwaters to mouth (Big Spring Cr)	P	XNX
Impaired	200501	8/9/2000	10040103	MT41S001_020	JUDITH RIVER from Ross Fork to Big Spring Cr	P	SNX
Impaired	201301	9/19/2000	10070003	MT43A001_012	SHIELDS RIVER from headwaters to Cottonwood Cr	P	SXX
Impaired	206301	7/27/2000	10020004	MT41D004_120	ROCK CREEK from headwaters to mouth (Big Hole R)	P	SNX
Impaired	207101	7/19/2000	10020004	MT41D002_100	BIRCH CREEK from National Forest Boundary to mouth (Big Hole R)	N	SXX
Impaired	208101	7/17/2000	10020005	MT41G002_040	LITTLE PIPESTONE CREEK, Headwaters to mouth (Big Pipestone Cr)	P	SXX
Impaired	215701	6/21/2001	17010203	MT76F001_010	BLACKFOOT RIVER from headwaters to Landers Fork	N	XXM
Impaired	215901	6/21/2001	17010203	MT76F002_070	ARRASTRA CREEK from headwaters to mouth (Blackfoot R)	P	SXX
Impaired	216201	6/26/2001	17010203	MT76F002_030	POORMAN CREEK from headwaters to the mouth (Blackfoot R)	P	SXM
Impaired	216501	6/21/2001	17010203	MT76F002_020	WILLOW CREEK from Sandbar Cr to mouth, T15N R7W (Blackfoot R)	P	SXX
Impaired	216701	6/18/2001	17010203	MT76F002_060	SANDBAR CREEK from forks to mouth (Willow Cr)	P	SXM
Impaired	221201	6/28/2001	10020004	MT41D004_090	JOSEPH CREEK, Headwaters to mouth (Trail Cr-North Fork Big Hole R)	P	XXM
Impaired	225601	5/29/2001	10030205	MT41O002_010	WILLOW CREEK from headwaters to the mouth (Deep Cr)	P	SXX
Impaired	235801	8/1/2001	17010204	MT76M003_040	BIG CREEK from the East and Middle Forks to the mouth (ST. Regis R)	P	SXX
Impaired	235901	8/2/2001	17010204	MT76M003_020	TWELVEMILE CREEK from headwaters to the mouth (ST. Regis R)	P	SXX
Impaired	236001	8/8/2001	17010205	MT76H002_040	MOOSE CREEK from headwaters to the mouth (East Fork Bitterroot R)	P	SNX
Impaired	237101	8/10/2001	10020002	MT41B002_030	BLACKTAIL DEER CREEK from headwaters to mouth (Beaverhead R)	N	SXX
Impaired	249202	7/19/2002	10030104	MT41K001_010	SUN RIVER from Gibson Dam to Muddy Cr	N	SNX
Impaired	249501	7/12/2002	17010201	MT76G003_020	SILVER BOW CREEK from the Warm Springs Pond 2 outlet to headwaters	N	SNM
Impaired	261701	9/5/2002	17010211	MT76K003_010	JIM CREEK from West Fk to mouth (Swan R)	P	SXX
Impaired	263501	9/24/2002	10020003	MT41C002_100	GARDEN CREEK, Headwaters to mouth at Ruby Reservoir	P	SXX
Impaired	266302	7/22/2003	10030102	MT41Q003_030	SOUTH FORK OF THE DEARBORN RIVER, Headwaters to the mouth (Dearborn R)	P	SXX
Impaired	291201	8/14/2003	10020003	MT41C002_040	ALDER GULCH from headwaters to mouth (Ruby R)	N	SXM

Appendix A: Reference and Impaired Sample Listing, Plains Streams

Strata	Sample	Date	HUC	Segment ID	Segment Name	ALU	Cause(s)
Reference	64402	7/31/1979	10090102	CowCreek_141_W	Cow Creek	F	XXX
Reference	107201	8/23/1990	10060001	TuleCree_164_W	Tule Creek	F	XXX
Reference	113604	9/14/1995	10050010	WoodyIsl_174_W	Woody Island Coulee	F	XXX
Reference	187001	9/28/1999	10100005	MilkCree_416_W	Milk Creek near mouth	F	XXX
Reference	190701	9/22/1999	10090102	PumpkinC_161_W	Pumpkin Creek	F	XXX
Reference	213101	8/8/2000	10100005	OFallon9_157_W	O Fallon	F	XXX
Reference	213301	8/10/2000	10110201	LittleBe_410_W	Little Beaver Creek	F	XXX
Reference	213401	8/11/2000	10110202	BoxElder_137_W	Box Elder Creek	F	XXX
Reference	214001	8/25/2000	10050011	Whitewat_169_W	Whitewater Creek	F	XXX
Reference	219001	6/24/2001	10050015	WillowCr_171_W	Willow Creek	F	XXX
Reference	227201	8/1/2001	10100005	SpringCr_081_W	Spring Creek	F	XXX
Reference	237001	6/24/2001	10040104	CowCreek_022_W	Cow Creek	F	XXX
Reference	237701	10/11/2001	10090208	LittlePo_050_W	Little Powder River	F	XXX
Reference	237901	10/15/2001	10040201	FishCree_038_W	Fish Creek	F	XXX
Reference	259101	8/22/2002	10040101	EagleCre_030_W	Eagle Creek (Site 3)	F	XXX
Reference	300501	7/29/2003	10040106	LittleDr_151_W	Little Dry Cr.	F	XXX
Reference	302301	6/19/2003	10060002	E.Redwat_027_W	E. Redwater Creek	F	XXX
Reference	302501	6/20/2003	10060002	PastureC_065_W	Pasture Creek (Site 2)	F	XXX
Reference	304501	7/24/2003	10040103	BeaverCr_002_W	Beaver Creek	F	XXX
Reference	338801	8/7/2003	10050004	ClearCre_121_W	Clear Creek (Nut pilot)	F	XXX
Reference	339301	8/26/2003	10100005	OFallon9_156_W	O Fallon	F	XXX
Reference	339401	8/5/2003	10050015	RockCree_123_W	Rock Creek (Site 1)	F	XXX
Reference	339501	8/6/2003	10050015	RockCree_124_W	Rock Creek (Site 2)	F	XXX
Reference	340001	8/3/2003	10060001	WolfCree_130_W	Wolf Creek @ Wolf Pt.	F	XXX
Reference	340101	8/4/2003	10060004	WFkPopla_126_W	W. Fk. Poplar River	F	XXX
Other	11907	7/26/2001	10090102	MT42C001_011	TONGUE RIVER from diversion dam just above Pumpkin Cr to the mouth (Yellowstone R)	P	XXX
Other	30506	5/25/1999	10060002	MT40P001_014	REDWATER RIVER from Pasture Cr. to the mouth (Missouri R)	P	XXX
Other	74502	5/27/1999	10040106	MT40D004_010	LITTLE DRY CREEK, Headwaters to the mouth (Big Dry Cr)	F	XXX
Other	107502	6/26/2001	10100005	MT42L001_032	O'FALLON CREEK from Mildred to the Fallon/Carter Co. line	F	XXX
Other	156301	7/12/1995	10110201	MT39F001_021	LITTLE MISSOURI RIVER, Highway 323 bridge to the South Dakota Border	F	XXX
Other	180801	5/26/1999	10060002	MT40P001_011	REDWATER RIVER from headwaters to Hell Cr.	F	XXX
Other	181201	5/25/1999	10060002	MT40P001_013	REDWATER RIVER from Buffalo Springs Cr. to Pasture Cr.	F	XXX
Other	185702	8/28/2000	10090210	MT42J005_010	MIZPAH CREEK from headwaters to the mouth (Powder R)	F	XXX
Other	186701	9/29/1999	10100005	MT42L001_033	O'FALLON CREEK headwaters to Fallon/Carter Co. line.	F	XXX
Other	187501	7/29/1999	10040205	MT40C004_020	LODGEPOLE CREEK, North & Middle Fks confluence to the mouth (Musselshell)	F	XXX
Other	190001	8/21/1999	10040205	MT40C003_010	MUSSELSHELL RIVER, from Flatwillow Cr to Fort Peck Reservoir	P	XXX
Other	190301	9/23/1999	10110204	MT39G001_010	BEAVER CREEK, Headwaters to the North Dakota Border	F	XXX
Other	199101	7/28/2000	10070003	MT43A002_051	ROCK CREEK Little Rock Cr to the mouth (Shields R)	P	XXX
Other	199201	7/21/2000	10070002	MT43B004_052	BILLMAN CREEK from headwaters to Livingston City limits	F	XXX

Appendix A: Reference and Impaired Sample Listing, Plains Streams

Strata	Sample	Date	HUC	Segment ID	Segment Name	ALU	Cause(s)
Other	199801	8/10/2000	10070003	MT43A002_010	POTTER CREEK from headwaters to the mouth (Shields R)	P	XXX
Other	199901	8/11/2000	10070003	MT43A002_020	ANTELOPE CREEK from headwaters to the mouth (Shields R)	P	XXX
Other	214601	9/8/2000	10030204	MT41P004_010	WILLOW CREEK from headwaters to mouth at Tiber Reservoir	F	XXX
Other	217801	6/27/2001	10100005	MT42L001_031	O'FALLON CREEK from the mouth (Yellowstone R) to Mildred	F	XXX
Other	218401	6/28/2001	10100005	MT42L001_020	SANDSTONE CREEK from headwaters to the mouth (O'Fallon Cr)	F	XXX
Other	226601	7/14/2001	10040202	MT40C001_010	MUSSELSHELL RIVER, from HUC boundary SW of Roundup to Flatwillow Cr	P	XXX
Other	227401	8/3/2001	10100005	MT42L001_010	PENNEL CREEK from headwaters to the mouth (O'Fallon Cr)	F	XXX
Other	227601	8/5/2001	10110201	MT39F001_022	LITTLE MISSOURI RIVER, Wyoming border to the Highway 323 bridge.	F	XXX
Impaired	414	8/28/2002	10070003	MT43A001_011	SHIELDS RIVER from Cottonwood Cr. to the mouth (Yellowstone R)	P	SXX
Impaired	1709	8/2/2002	10040201	MT40A001_010	MUSSELSHELL RIVER, No & So Fk confluence to Deadmans Basin Diversion Canal	P	SNX
Impaired	3706	7/9/2001	10040103	MT41S001_010	JUDITH RIVER from Big Spring Cr to the mouth (Missouri R)	P	SXX
Impaired	38104	9/21/2000	10040202	MT40A001_020	MUSSELSHELL RIVER, Deadmans Basin Div. Canal to HUC boundary near Roundup	P	SNX
Impaired	52904	9/20/1999	10100003	MT42A001_011	ROSEBUD CREEK, From the mouth 3.8 mi upstream to an irrigation dam	P	SXX
Impaired	156801	7/22/1995	10030204	MT41P004_020	EAGLE CREEK from headwaters to mouth at Tiber Reservoir.	P	SNX
Impaired	157301	8/21/1995	10060001	MT40S002_030	SAND CREEK from the forks to the mouth (Missouri R)	P	SNX
Impaired	157401	8/10/1995	10060001	MT40S002_010	PRAIRIE ELK CREEK from the East and Middle Forks to the mouth (Missouri R)	P	XNX
Impaired	190101	7/16/1999	10040104	MT40E003_020	NELSON CREEK, Headwaters to the mouth (Big Dry Cr Arm of Fort Peck Res)	P	XNX
Impaired	195401	6/6/2000	10060006	MT40R001_020	BIG MUDDY CREEK from Canada to northern boundary of Fort Peck Reservation	P	XNM
Impaired	196101	6/6/2000	10060006	MT40R001_010	BIG MUDDY CREEK northern Fort Peck Res. boundary to the mouth (Missouri R)	P	SNX
Impaired	198701	8/23/2000	10040105	MT40D001_010	BIG DRY CREEK, Steves Fork to mouth (Fort Peck Reservoir)	P	XNX
Impaired	208801	7/13/2000	10030102	MT41Q003_040	FLAT CREEK from Henry Cr to the mouth (Dearborn R)	P	SXX
Impaired	219601	8/21/2001	10040103	MT41S004_052	COTTONWOOD CREEK from county road bridge at T14N R18E Sec18 to mouth (Big Spring Cr	P	SNX
Impaired	219801	8/24/2001	10050012	MT40O002_030	WILLOW CREEK, mainstem plus North Fork below Halfpint Reservoir	P	SXX
Impaired	225401	5/30/2001	10030205	MT41O002_060	TETON SPRING CREEK from the city of Choteau to mouth (Teton R)	P	SNX
Impaired	225701	5/29/2001	10030205	MT41O002_020	DEEP CREEK from Willow Cr to the mouth (Teton R)	P	SNX
Impaired	228501	8/29/2001	10090101	MT42B002_031	HANGING WOMAN CREEK from Stroud Cr to the mouth (Tongue R)	P	SXX
Impaired	289101	7/24/2003	10030102	MT41Q003_010	DEARBORN RIVER from Falls Cr to the mouth (Missouri R)	N	SXX
Impaired	349701	10/4/2004	10040203	MT40B001_022	FLATWILLOW CREEK, Highway 87 bridge to the mouth (Musselshell R)	P	SNM

Appendix B: Similarity Matrix of Reference Samples

Region		M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
	Sample	13003	34301	48601	75213	76102	77901	101402	103201	105107	105502	105703	105903	106001	106201	106301	106501	106602	106701	106901	140212	149701	201501	206801	224902	235001	235101	237301	237401	237501	251901	261201	263301	263701	267101
M	13003	100	0	0	37	0	0	54	0	0	0	34	24	42	62	21	0	0	46	8	0	10	10	7	0	0	0	0	0	0	0	0	0	0	0
M	34301	0	100	50	4	35	47	8	20	33	44	5	6	6	5	5	4	27	2	8	34	12	6	12	37	56	26	44	60	21	43	27	26	34	54
M	48601	0	50	100	2	31	51	16	14	24	43	5	3	4	6	6	4	17	2	14	27	5	4	6	35	77	30	39	75	13	31	27	27	20	59
M	75213	37	4	2	100	3	9	43	4	6	4	43	34	66	39	29	5	8	55	13	11	15	26	12	8	5	6	5	4	8	8	6	4	6	4
M	76102	0	35	31	3	100	33	4	17	23	31	1	1	4	3	2	1	14	4	3	33	1	2	2	29	34	21	32	32	25	37	30	23	16	37
M	77901	0	47	51	9	33	100	7	17	21	38	6	11	10	5	17	12	30	12	15	36	6	20	6	34	55	28	35	52	17	37	26	33	25	50
M	101402	54	8	16	43	4	7	100	3	14	5	34	28	41	62	37	8	12	46	35	6	16	19	12	11	14	17	10	11	7	3	3	8	10	3
M	103201	0	20	14	4	17	17	3	100	19	16	2	2	1	1	2	0	14	3	3	18	6	3	5	18	17	17	18	14	17	28	11	22	18	20
M	105107	0	33	24	6	23	21	14	19	100	32	8	9	8	9	17	14	37	8	19	33	16	14	32	36	30	42	40	30	37	26	13	26	30	19
M	105502	0	44	43	4	31	38	5	16	32	100	4	11	11	4	8	6	19	12	8	32	10	9	14	40	40	25	45	52	16	34	26	29	25	37
M	105703	34	5	5	43	1	6	34	2	8	4	100	35	46	39	32	6	10	35	16	6	19	23	7	8	7	8	9	6	6	4	0	7	9	3
M	105903	24	6	3	34	1	11	28	2	9	11	35	100	35	28	32	7	10	29	19	17	23	35	13	15	4	9	9	8	7	5	0	5	13	1
M	106001	42	6	4	66	4	10	41	1	8	11	46	35	100	47	37	10	12	61	16	11	23	23	17	13	5	6	13	9	9	3	1	5	14	2
M	106201	62	5	6	39	3	5	62	1	9	4	39	28	47	100	37	4	8	50	27	3	13	17	15	12	9	11	5	6	5	3	0	4	4	3
M	106301	21	5	6	29	2	17	37	2	17	8	32	32	37	37	100	24	28	31	52	15	18	32	11	22	10	25	20	6	11	7	0	12	14	3
M	106501	0	4	4	5	1	12	8	0	14	6	6	7	10	4	24	100	27	8	23	6	8	14	9	31	5	15	10	6	8	2	0	5	8	1
M	106602	0	27	17	8	14	30	12	14	37	19	10	10	12	8	28	27	100	9	22	29	21	18	15	30	21	27	31	21	29	25	11	20	27	13
M	106701	46	2	2	55	4	12	46	3	8	12	35	29	61	50	31	8	9	100	12	6	9	19	5	8	5	7	5	3	5	6	1	5	6	1
M	106901	8	8	14	13	3	15	35	3	19	8	16	19	16	27	52	23	22	12	100	17	15	32	12	31	15	30	21	10	10	9	0	10	13	3
M	140212	0	34	27	11	33	36	6	18	33	32	6	17	11	3	15	6	29	6	17	100	12	20	13	40	32	29	34	32	35	35	19	29	32	28
M	149701	10	12	5	15	1	6	16	6	16	10	19	23	23	13	18	8	21	9	15	12	100	19	19	13	6	7	22	12	13	9	1	7	22	2
M	201501	10	6	4	26	2	20	19	3	14	9	23	35	23	17	32	14	18	19	32	20	19	100	19	20	7	17	9	7	12	7	0	9	15	2
M	206801	7	12	6	12	2	6	12	5	32	14	7	13	17	15	11	9	15	5	12	13	19	19	100	16	9	19	23	11	13	8	0	8	15	4
M	224902	0	37	35	8	29	34	11	18	36	40	8	15	13	12	22	31	30	8	31	40	13	20	16	100	40	43	45	43	24	33	23	29	29	31
M	235001	0	56	77	5	34	55	14	17	30	40	7	4	5	9	10	5	21	5	15	32	6	7	9	40	100	38	46	78	17	37	27	27	22	64
M	235101	0	26	30	6	21	28	17	17	42	25	8	9	6	11	25	15	27	7	30	29	7	17	19	43	38	100	40	30	18	24	16	30	28	21
M	237301	0	44	39	5	32	35	10	18	40	45	9	9	13	5	20	10	31	5	21	34	22	9	23	45	46	40	100	48	22	39	26	31	35	36
M	237401	0	60	75	4	32	52	11	14	30	52	6	8	9	6	6	6	21	3	10	32	12	7	11	43	78	30	48	100	15	32	27	26	26	62
M	237501	0	21	13	8	25	17	7	17	37	16	6	7	9	5	11	8	29	5	10	35	13	12	13	24	17	18	22	15	100	28	9	17	22	15
M	251901	0	43	31	8	37	37	3	28	26	34	4	5	3	3	7	2	25	6	9	35	9	7	8	33	37	24	39	32	28	100	36	28	22	39
M	261201	0	27	27	6	30	26	3	11	13	26	0	0	1	0	0	0	11	1	0	19	1	0	0	23	27	16	26	27	9	36	100	20	13	29
M	263301	0	26	27	4	23	33	8	22	26	29	7	5	5	4	12	5	20	5	10	29	7	9	8	29	27	30	31	26	17	28	20	100	33	23
M	263701	0	34	20	6	16	25	10	18	30	25	9	13	14	4	14	8	27	6	13	32	22	15	15	29	22	28	35	26	22	22	13	33	100	18
M	267101	0	54	59	4	37	50	3	20	19	37	3	1	2	3	3	1	13	1	3	28	2	2	4	31	64	21	36	62	15	39	29	23	18	100
M	297901	0	20	22	4	27	21	8	21	44	23	7	3	4	3	11	6	23	3	9	31	8	5	25	23	26	26	29	21	29	28	13	24	23	23
M	338901	0	53	65	4	32	51	6	23	30	42	5	3	4	4	7	5	17	2	8	28	5	5	14	34	70	36	46	69	16	37	26	28	21	63
M	339001	0	41	39	4	48	37	9	26	35	36	7	2	3	7	7	5	19	1	8	39	6	4	5	35	45	28	41	42	38	45	28	27	21	43
M	339101	0	25	12	6	21	15	4	13	27	15	4	6	7	3	7	4	22	3	8	26	10	7	10	25	16	17	23	16	39	21	8	11	20	18
M	339601	0	45	66	1	29	47	4	15	16	36	1	0	0	1	1	0	12	0	2	20	2	1	4	25	65	20	31	65	9	30	26	22	16	57
P	64402	0	21	15	4	14	30	3	23	21	20	4	9	7	2	8	4	21	4	9	25	10	17	9	24	14	18	22	18	17	21	12	33	25	13
P	107201	7	3	1	12	2	5	8	10	7	4	9	8	11	10	12	1	7	9	11	6	11	12	9	5	3	4	5	0	13	24	1	12	6	3
P	113604	26	3	1	37	1	6	29	1	4	1	35	30	35	29	30	3	9	34	9	5	16	17	11	3	3	3	4	1	5	7	1	3	5	1
P	187001	1	3	2	3	1	5	3	1	5	3	5	10	3	2	6	4	8	4	9	6	6	7	3	6	2	3	4	3	4	7	1	8	4	1
P	190701	0	0	0	2	1	6	1	3	2	3	2	8	2	1	6	0	4	2	3	2	5	5	1	4	1	3	2	0	4	5	0	8	2	0
P	213101	1	1	1	9	1	3	1	0	2	2	7	3	7	1	2	0	4	2	3	1	3	3	1	1	1	1	1	1	2	6	0	3	1	0
P	213301	9	7	3	12	2	5	7	2	9	10	7	16	17	13	9	5	10	6	10	12	18	13	35	12	4	4	10	9	10	8	1	6	10	2
P	213401	6	1	0	8	1	5	5	2	2	3	3	7	7	8	7	0	6	4	8	5	6	7	7	2	1	2	0	0	3	8	0	6	2	0
P	214001	0	0	1	3	1	5	2	0	2	2	2	7	2	2	3	1	6	1	4	3	2	2	8	2	1	1	1	1	2	6	0	5	1	1
P	219001	0	1	2	2	1	5	4	2	5	2	5	3	2	1	14	5	12	2	16	8	7	9	3	8	4	5	10	2	4	10	0	5	7	1
P	227201	0	3	3	4	2	5	2	4	6	4	4	11	3	1	6	4	7	2	5	5	7	5	5	7	3	3	5	3	7	8	0	8	4	2
P	237001	0	0	1	0	4	1	0	1	9	30	0	0	0	1	1	0	1	8	1	4	0	0	0	1	0	1	3	1	4	3	0	2	1	1
P	237701	0	0	0	1	1	4	0	0	1	1	0	5	0	0	1	0	3	0	2	1	0	0	0	0	0	0	0	0	1	3	0	4	1	0
P	237901	0	12	9	11	11	16	4	9	15	12	6	14	9	3	10	6	21	5	9	21	9	12	6	19	11	12	14	12	22	27	11	15	13	10
P	259101	0	1	1	2	4	8	0	3	3	2	0	4	1	0	6	0	4	2	5	8	1	5	1	6	2	4	1	1	4	7	0	4	5	1
P	300501	0	32	28	3	35	37	1	15	14	28	1	2	3	1	8	2	16	4	7	25	2	5	4	27	30	19	30	29	12	43	34	25	15	32
P	302301	0	0	0	0	0	4	0	0	0	0	0	6	0	0	2	0	3	0	3	2	1	1	0	1	0	0	0	0	1	4	0	2	1	0
P	302501	0	0	0	0	2	3	0	0	0	0	0	6	0	0	2	0	3	0	6	4	1	3	0	1	0	0	0	0	1	6	0	3	0	1
P	304501	0	7	3	13	5	24	4	4	6	3	3	9	6	3	10	3	9	7	10	14	1	17	4	9	8	9	13	4	7	9	1	5	8	8
P	338801	0	14	5	13	6	23	6	13	15	12	4	14	14	3	13	5	18	8	15	22	16	15	15	19	9	11	20	12	18	21	1	16	24	6
P	339301	0	1	1	2	1	3	1	2	2	2	0	4	1	1	2	0	3	1	1	2	3	1	0	1	0	2	0	0	4	5	0	6	2	1
P	339401	0	1	1	8	4	9	2	5	3	3	1	5	3	2	7	0	5	2	5	12	2	4	2	4	2	5	1	0	6	10	0	9	5	2
P	339501	0	3	4	3	5	10	4	7	7	4	5	5	2	1	5	3	11	2	6	12	7	3	2	5	5	8	7	5	9	11	2	12	9	4
P	340001	0	9	5	6	9	9	2	11	13	13	3	14	11	1	4	4	10	3	5	20	15	7	12	14	5	6	14	12	18	24	3	12	18	6
P	340101	0	13	10	8	10	14	3	12	15	16	4	10	13	1	7	6	16	6	6	22	16	10	14	19	11	11	21	17	18	18	7	12	22	11

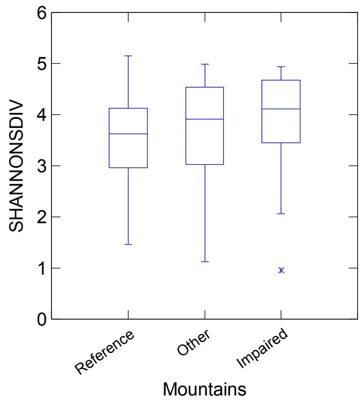
Appendix B: Similarity Matrix of Reference Samples

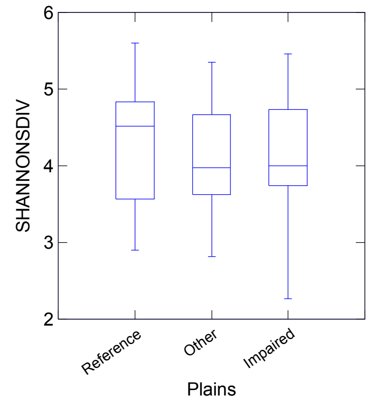
Region		M	M	M	M	M	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
	Sample	297901	338901	339001	339101	339601	64402	107201	113604	187001	190701	213101	213301	213401	214001	219001	227201	237001	237701	237901	259101	300501	302301	302501	304501	338801	339301	339401	339501	340001	340101
M	13003	0	0	0	0	0	0	7	26	1	0	1	9	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M	34301	20	53	41	25	45	21	3	3	3	0	1	7	1	0	1	3	0	0	12	1	32	0	0	7	14	1	1	3	9	13
M	48601	22	65	39	12	66	15	1	1	2	0	1	3	0	1	2	3	1	0	9	1	28	0	0	3	5	1	1	4	5	10
M	75213	4	4	4	6	1	4	12	37	3	2	9	12	8	3	2	4	0	1	11	2	3	0	0	13	13	2	8	3	6	8
M	76102	27	32	48	21	29	14	2	1	1	1	1	2	1	1	1	2	4	1	11	4	35	0	2	5	6	1	4	5	9	10
M	77901	21	51	37	15	47	30	5	6	5	6	3	5	5	5	5	5	1	4	16	8	37	4	3	24	23	3	9	10	9	14
M	101402	8	6	9	4	4	3	8	29	3	1	1	7	5	2	4	2	0	0	4	0	1	0	0	4	6	1	2	4	2	3
M	103201	21	23	26	13	15	23	10	1	1	3	0	2	2	0	2	4	1	0	9	3	15	0	0	4	13	2	5	7	11	12
M	105107	44	30	35	27	16	21	7	4	5	2	2	9	2	2	5	6	9	1	15	3	14	0	0	6	15	2	3	7	13	15
M	105502	23	42	36	15	36	20	4	1	3	3	2	10	3	2	2	4	30	1	12	2	28	0	0	3	12	2	3	4	13	16
M	105703	7	5	7	4	1	4	9	35	5	2	7	7	3	2	5	4	0	0	6	0	1	0	0	3	4	0	1	5	3	4
M	105903	3	3	2	6	0	9	8	30	10	8	3	16	7	7	3	11	0	5	14	4	2	6	6	9	14	4	5	5	14	10
M	106001	4	4	3	7	0	7	11	35	3	2	7	17	7	2	2	3	0	0	9	1	3	0	0	6	14	1	3	2	11	13
M	106201	3	4	7	3	1	2	10	29	2	1	1	13	8	2	1	1	1	0	3	0	1	0	0	3	3	1	2	1	1	1
M	106301	11	7	7	7	1	8	12	30	6	6	2	9	7	3	14	6	1	1	10	6	8	2	2	10	13	2	7	5	4	7
M	106501	6	5	5	4	0	4	1	3	4	0	0	5	0	1	5	4	0	0	6	0	2	0	0	3	5	0	0	3	4	6
M	106602	23	17	19	22	12	21	7	9	8	4	4	10	6	6	12	7	1	3	21	4	16	3	3	9	18	3	5	11	10	16
M	106701	3	2	1	3	0	4	9	34	4	2	2	6	4	1	2	2	8	0	5	2	4	0	0	7	8	1	2	2	3	6
M	106901	9	8	8	8	2	9	11	9	9	3	3	10	8	4	16	5	1	2	9	5	7	3	6	10	15	1	5	6	5	6
M	140212	31	28	39	26	20	25	6	5	6	2	1	12	5	3	8	5	4	1	21	8	25	2	4	14	22	2	12	12	20	22
M	149701	8	5	6	10	2	10	11	16	6	5	3	18	6	2	7	7	0	0	9	1	2	1	1	1	16	3	2	7	15	16
M	201501	5	5	4	7	1	17	12	17	7	5	3	13	7	2	9	5	0	0	12	5	5	1	3	17	15	1	4	3	7	10
M	206801	25	14	5	10	4	9	9	11	3	1	1	35	7	8	3	5	0	0	6	1	4	0	0	4	15	0	2	2	12	14
M	224902	23	34	35	25	25	24	5	3	6	4	1	12	2	2	8	7	1	0	19	6	27	1	1	9	19	1	4	5	14	19
M	235001	26	70	45	16	65	14	3	3	2	1	1	4	1	1	4	3	0	0	11	2	30	0	0	8	9	0	2	5	5	11
M	235101	26	36	28	17	20	18	4	3	3	3	1	4	2	1	5	3	1	0	12	4	19	0	0	9	11	2	5	8	6	11
M	237301	29	46	41	23	31	22	5	4	4	2	1	10	0	1	10	5	3	0	14	1	30	0	0	13	20	0	1	7	14	21
M	237401	21	69	42	16	65	18	0	1	3	0	1	9	0	1	2	3	1	0	12	1	29	0	0	4	12	0	0	5	12	17
M	237501	29	16	38	39	9	17	13	5	4	4	2	10	3	2	4	7	4	1	22	4	12	1	1	7	18	4	6	9	18	18
M	251901	28	37	45	21	30	21	24	7	7	5	6	8	8	6	10	8	3	3	27	7	43	4	6	9	21	5	10	11	24	18
M	261201	13	26	28	8	26	12	1	1	1	0	0	1	0	0	0	0	0	0	11	0	34	0	0	1	1	0	0	2	3	7
M	263301	24	28	27	11	22	33	12	3	8	8	3	6	6	5	5	8	2	4	15	4	25	2	3	5	16	6	9	12	12	12
M	263701	23	21	21	20	16	25	6	5	4	2	1	10	2	1	7	4	1	1	13	5	15	1	0	8	24	2	5	9	18	22
M	267101	23	63	43	18	57	13	3	1	1	0	0	2	0	1	1	2	1	0	10	1	32	0	1	8	6	1	2	4	6	11
M	297901	100	27	41	19	18	17	9	3	3	2	2	4	2	2	8	5	5	1	10	4	18	1	1	5	10	2	6	9	13	14
M	338901	27	100	45	24	61	16	3	0	2	0	1	4	0	1	2	3	0	0	9	0	29	0	0	3	8	0	2	4	8	12
M	339001	41	45	100	32	34	14	11	1	1	1	0	3	0	1	5	2	4	0	8	2	31	0	0	5	13	1	4	7	15	13
M	339101	19	24	32	100	10	14	5	3	2	0	1	7	1	1	1	4	2	0	13	2	10	0	0	9	14	0	4	3	14	17
M	339601	18	61	34	10	100	12	1	0	0	0	0	1	0	0	0	1	1	0	5	1	27	0	0	2	4	1	1	2	3	8
P	64402	17	16	14	14	12	100	10	3	15	16	12	16	15	13	10	18	4	11	24	13	22	9	7	16	29	11	17	19	22	20
P	107201	9	3	11	5	1	10	100	14	13	12	8	15	14	9	11	13	0	4	19	9	10	4	5	4	16	8	12	9	21	10
P	113604	3	0	1	3	0	3	14	100	5	5	8	13	9	10	7	6	2	3	8	4	3	1	2	4	7	9	10	5	6	7
P	187001	3	2	1	2	0	15	13	5	100	36	19	14	20	19	9	31	5	17	27	11	7	30	35	4	10	14	15	22	20	5
P	190701	2	0	1	0	0	16	12	5	36	100	29	9	30	17	9	22	7	37	31	21	22	18	28	4	9	25	27	36	17	4
P	213101	2	1	0	1	0	12	8	8	19	29	100	13	51	23	9	26	6	41	20	14	14	11	11	3	6	37	31	29	19	4
P	213301	4	4	3	7	1	16	15	13	14	9	13	100	23	34	6	15	1	7	20	7	4	7	7	4	17	10	15	12	24	16
P	213401	2	0	0	1	0	15	14	9	20	30	51	23	100	31	11	27	8	44	25	18	16	11	10	4	12	40	40	39	19	6
P	214001	2	1	1	1	0	13	9	10	19	17	23	34	31	100	5	37	2	18	21	11	10	18	13	4	10	13	15	14	15	3
P	219001	8	2	5	1	0	10	11	7	9	9	9	6	11	5	100	8	1	8	12	16	9	3	8	2	5	16	14	16	22	6
P	227201	5	3	2	4	1	18	13	6	31	22	26	15	27	37	8	100	6	18	24	14	11	32	16	3	12	16	16	17	21	8
P	237001	5	0	4	2	1	4	0	2	5	7	6	1	8	2	1	6	100	6	2	7	4	1	2	0	2	7	6	8	7	2
P	237701	1	0	0	0	0	11	4	3	17	37	41	7	44	18	8	18	6	100	22	18	19	14	13	4	8	37	35	46	17	2
P	237901	10	9	8	13	5	24	19	8	27	31	20	20	25	21	12	24	2	22	100	13	24	17	23	14	23	24	28	36	34	21
P	259101	4	0	2	2	1	13	9	4	11	21	14	7	18	11	16	14	7	18	13	100	15	9	9	4	8	13	17	19	12	5
P	300501	18	29	31	10	27	22	10	3	7	22	14	4	16	10	9	11	4	19	24	15	100	9	7	8	9	15	16	20	10	11
P	302301	1	0	0	0	0	9	4	1	30	18	11	7	11	18	3	32	1	14	17	9	9	100	25	4	7	11	10	20	14	2
P	302501	1	0	0	0	0	7	5	2	35	28	11	7	10	13	8	16	2	13	23	9	7	25	100	3	6	13	11	19	21	3
P	304501	5	3	5	9	2	16	4	4	4	4	3	4	4	4	2	3	0	4	14	4	8	4	3	100	25	2	10	7	5	7
P	338801	10	8	13	14	4	29	16	7	10	9	6	17	12	10	5	12	2	8	23	8	9	7	6	25	100	10	21	15	34	31
P	339301	2	0	1	0	1	11	8	9	14	25	37	10	40	13	16	16	7	37	24	13	15	11	13	2	10	100	50	35	25	7
P	339401	6	2	4	4	1	17	12	10	15	27	31	15	40	15	14	16	6	35	28	17	16	10	11	10	21	50	100	46	30	13
P	339501	9	4	7	3	2	19	9	5	22	36	29	12	39	14	16	17	8	46	36	19	20	20	19	7	15	35	46	100	34	16
P	340001	13	8	15	14	3	22	21	6	20	17	19	24	19	15	22	21	7	17	34	12	10	14	21	5	34	25	30	34	100	35
P	340101	14	12	13	17	8	20	10	7	5	4	4	16	6	3	6	8	2	2	21	5	11	2	3	7	31	7	13	16	35	100

Appendix C: Overview of Potential Metrics

Shannon Diversity Index

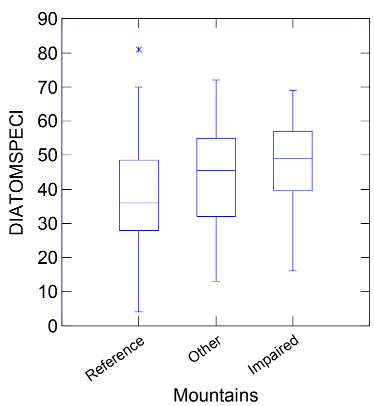
Weber (1973) using log base 2
Expected Trend in Mountain Streams: Convex Hyperbolic
Expected Trend in Plains Streams: Nonlinear Decreasing

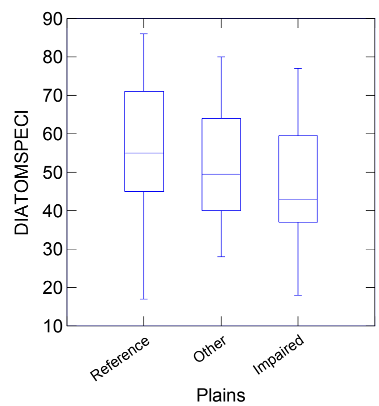




Diatom Species Richness

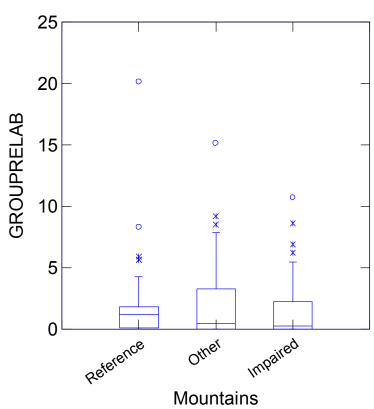
Total number of species counted (during proportional count)
Expected Trend in Mountain Streams: Convex Hyperbolic
Expected Trend in Plains Streams: Nonlinear Decreasing

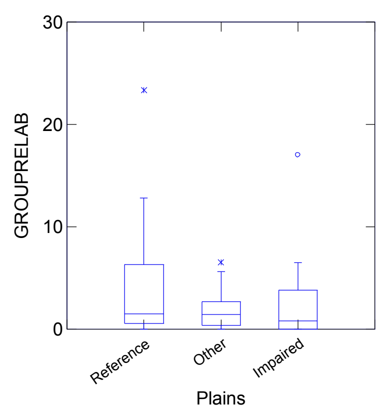




% Native Diatom Species

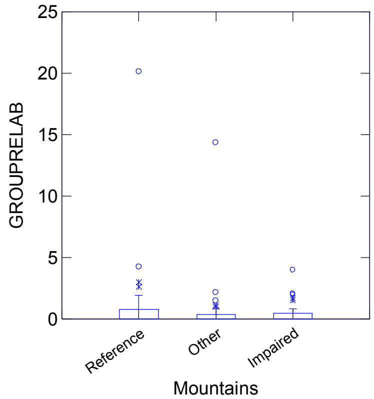
Percent relative abundance (PRA) of species native to Montana (230 spp.)
Expected trend in Mountain Streams: Linear Decreasing
Expected trend in Plains Streams: Linear Decreasing

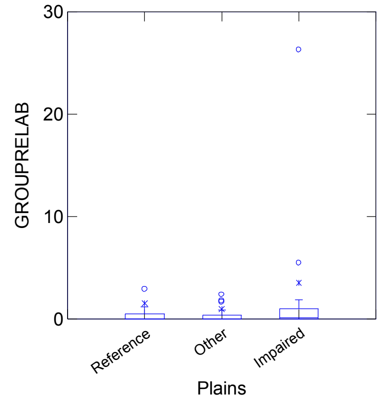




% Rare Diatom Species

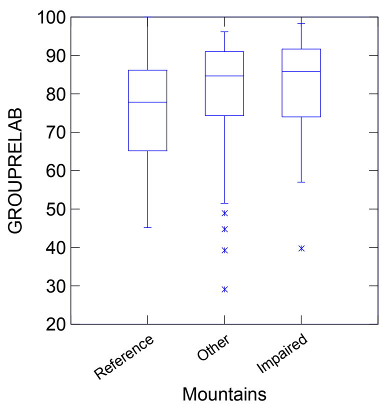
Percent relative abundance (PRA) of diatom species occurring in PRA greater than 2 percent in at least one sample and present in less than 10 percent of stations in MDD
Expected trend in Mountain Streams: Linear Decreasing
Expected trend in Plains Streams: Linear Decreasing

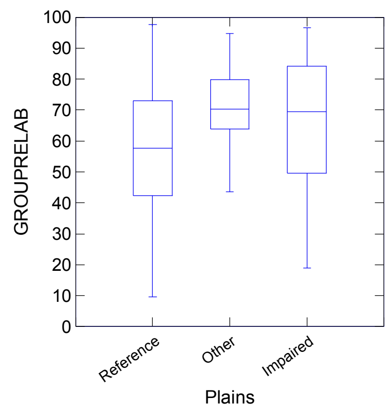




% Cosmopolitan Diatom Species

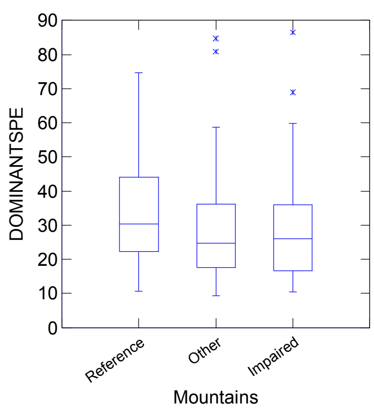
Percent relative abundance (PRA) cosmopolitan species (242 spp.)
Expected trend in Mountain Streams: Linear Increasing
Expected trend in Plains Streams: Linear Increasing

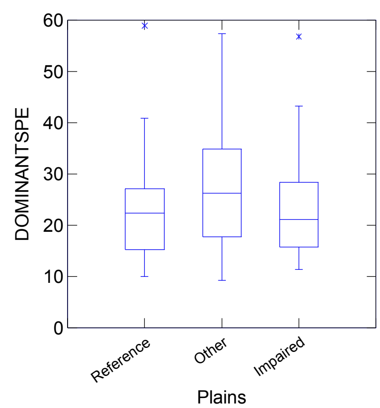




% Dominant Diatom Species

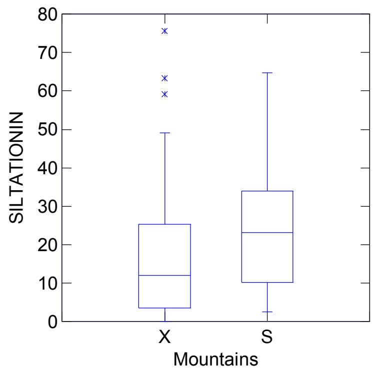
Percent relative abundance (PRA) of dominant species counted
Expected Trend in Mountain Streams: Concave Hyperbolic
Expected Trend in Plains Streams: Nonlinear Increasing

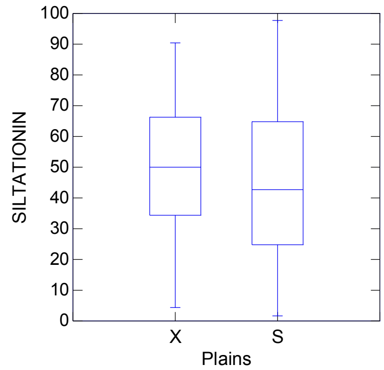




Siltation Index

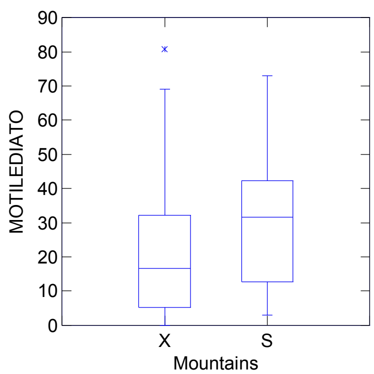
PRA of [***Navicula*** *(Cavinula + Craticula + Diadesmis + Dickieia + Fallacia + Geissleria + Hippodonta + Luticola + Navicula + Placoneis + Sellaphora + Proshkinia + Kobayasiella + Aneumastus)* + ***Nitzschia*** *(Nitzschia + Simonsenia + Tryblionella)* + ***Surirella***]
Expected Trend in Mountain Streams: Linear Increasing
Expected Trend in Plains Streams: Linear Increasing

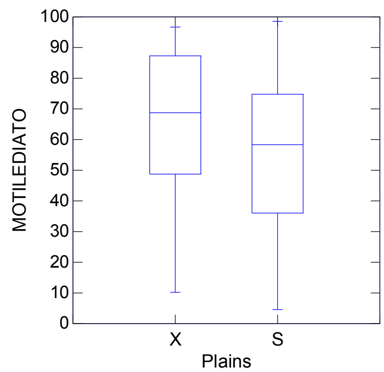




% Motile Diatoms

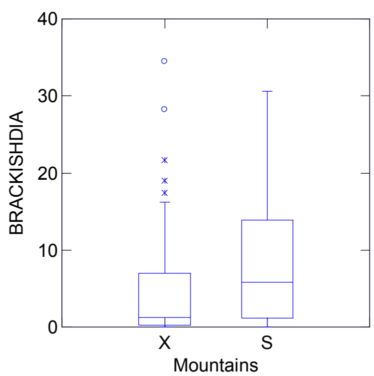
PRA of highly motile and moderately motile diatoms (with raphes, but not highly motile)
Expected Trend in Mountain Streams: Linear Increasing
Expected Trend in Plains Streams: Linear Increasing

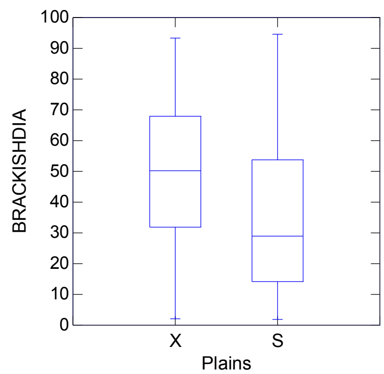




% Brackish Diatoms

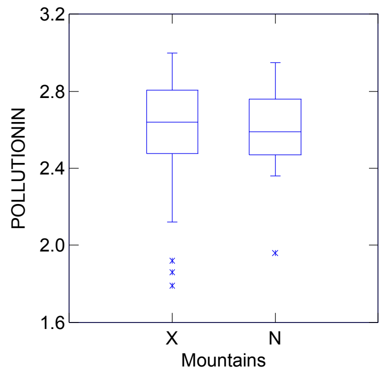
PRA of brackish diatoms (plains streams) or brackish and brackish fresh diatoms (mountain streams)
Expected Trend in Mountain Streams: Linear Increasing
Expected Trend in Plains Streams: Linear Increasing

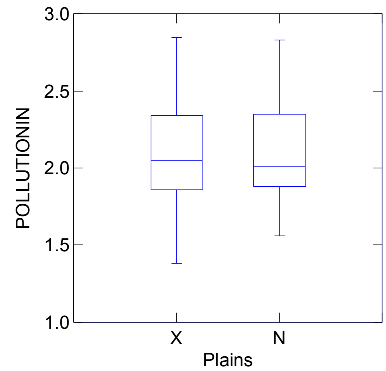




Pollution index

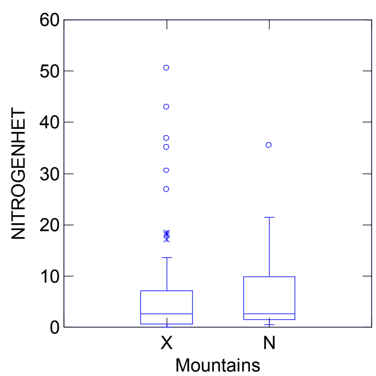
Aggregate index based on pollution tolerance (Lange-Bertalot 1979)
Expected Trend in Mountain Streams: Nonlinear Decreasing
Expected Trend in Plains Streams: Nonlinear Decreasing

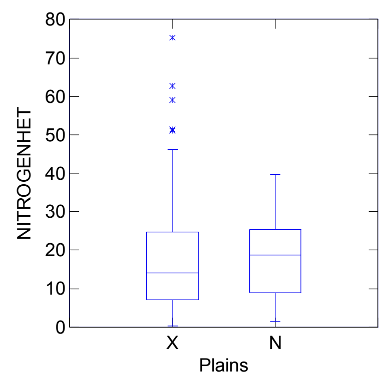




% Nitrogen Heterotrophs

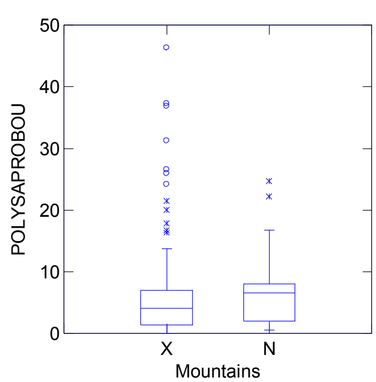
PRA of facultative heterotrophs and obligate nitrogen heterotrophs
Expected Trend in Mountain Streams: Linear Increasing
Expected Trend in Plains Streams: Linear Increasing

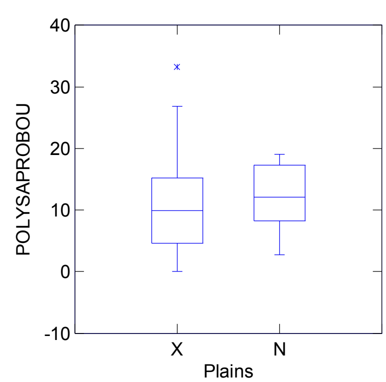




% Polysaprobous Diatoms

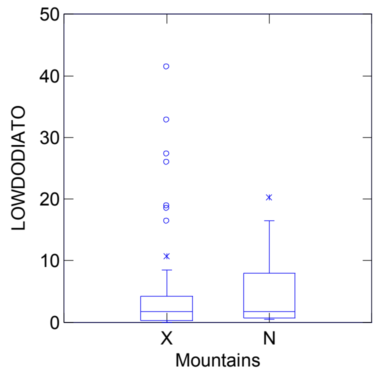
PRA of alpha-mesosaprobous, alpha-meso/polysaprobous, and polysaprobous diatoms
Expected Trend in Mountain Streams: Linear Increasing
Expected Trend in Plains Streams: Linear Increasing

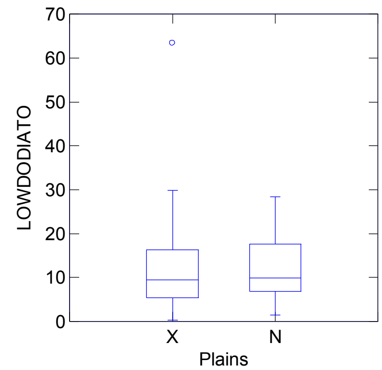




% Low Dissolved Oxygen Demand Diatoms

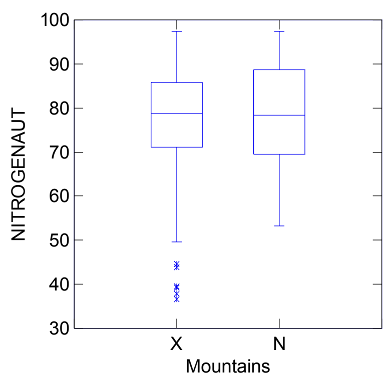
PRA of low and very low oxygen demand diatoms
Expected Trend in Mountain Streams: Linear Increasing
Expected Trend in Plains Streams: Linear Increasing

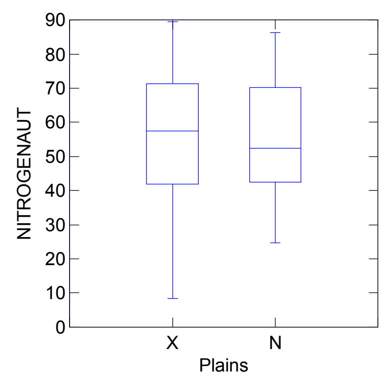




% Nitrogen Autotrophs

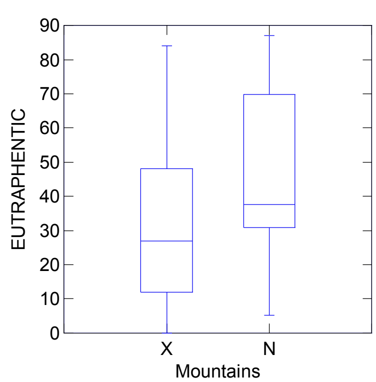
PRA of nitrogen autotroph (tolerates small concentrations of organic N) and nitrogen autotroph (tolerates elevated concentrations of organic N)
Expected Trend in Mountain Streams: Linear Decreasing
Expected Trend in Plains Streams: Linear Decreasing

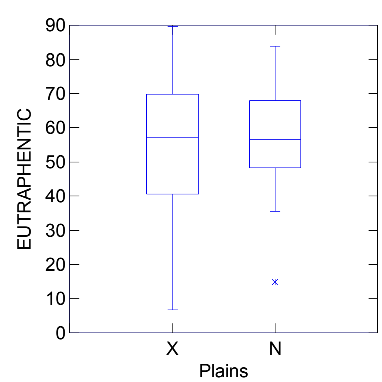




% Eutraphentic Diatoms

PRA of eutraphentic and hypereutraphentic diatoms
Expected Trend in Mountain Streams: Linear Increasing
Expected Trend in Plains Streams: Linear Increasing

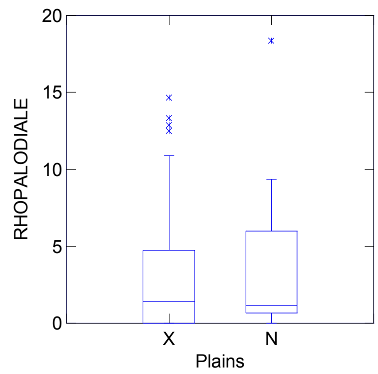




% Rhopalodiales

PRA of (*Epithemia* + *Rhopalodia*)

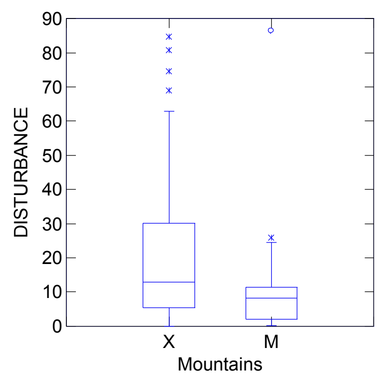
Expected Trend in Plains Streams: Linear Decreasing



Disturbance index

PRA of *Achnanthidium minutissimum* (new name) or % *Achnanthes minutissima*

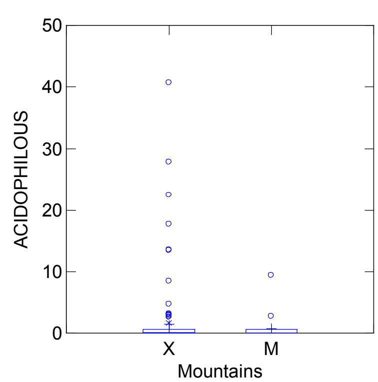
Expected Trend in Mountain Streams: Concave Hyperbolic



% Acidophilous Diatoms

PRA of acidobiontic and acidophilous diatoms

Expected Trend in Mountain Streams: Concave Hyperbolic

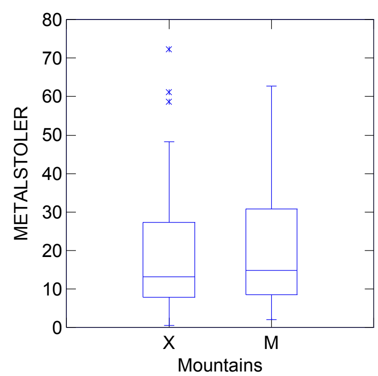


% Metals Tolerant Diatoms

PRA of diatom species known to tolerate elevated concentrations of heavy metals:

Taxa	Synonyms
Adlafia minuscula	*Navicula minuscula*
Encyonema minutum	*Cymbella minutua*
Encyonema silesiacum	*Cymbella silesiaca*
Fragilaria capucina	
Fragilaria vaucheriae	*F. capucina var. vaucheriae*
Gomphonema parvulum	
Mayamaea atomus	*Navicula atomus*
M. atomus var. permitis	*Navicula permitis*
Navicula arvensis	
Navicula minima[2]	*Eolimna minima*
Nitzschia palea	
Planothidium lanceolatum	*Achnanthes lanceolata*
Planothidium dubium	*A. lanceolata var. dubia*
Surirella angusta	
Surirella minuta	*Surirella ovata*
Synedra rumpens	*Fragilaria capucina v. rumpens*
Synedra ulna	*Fragilaria ulna*
Sellaphora seminulum	*Navicula seminulum*

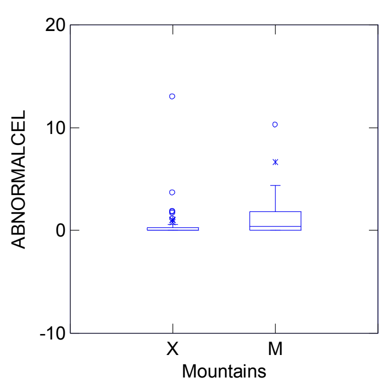
Expected Trend in Mountain Streams: Linear Increasing



% Abnormal Cells

PRA of cells exhbiting teratogenic effects

Expected Trend in Mountain Streams: Linear Increasing



Appendix D. Diatom association metrics used by the State of Montana to evaluate biological integrity in mountain streams: references, range of values, expected response to increasing impairment or natural stress, and criteria for rating levels of biological integrity. The lowest rating for any one metric is the rating for that site.

Biological Integrity/ Impairment or Stress/ Use Support	No. of Species Counted[1]	Diversity Index[2] (Shannon)	Pollution Index[3]	Siltation Index[4]	Disturbance Index[5]	% Dominant Species[6]	% Abnormal Cells[7]
Excellent/None Full Support	>29	>2.99	>2.50	<20.0	<25.0	<25.0	0
Good/Minor Full Support	20-29	2.00-2.99	2.01-2.50	20.0-39.9	25.0-49.9	25.0-49.9	>0.0, <3.0
Fair/Moderate Partial Support	19-10	1.00-1.99	1.50-2.00	40.0-59.9	50.0-74.9	50.0-74.9	3.0-9.9
Poor/Severe Nonsupport	<10	<1.00	<1.50	>59.9	>74.9	>74.9	>9.9
References	Bahls 1979 Bahls 1993	Bahls 1979	Bahls 1993	Bahls 1993	Barbour et al. 1999	Barbour et al. 1999	McFarland et al. 1997
Range of Values	0-100+	0.00-5.00+	1.00-3.00	0.0-90.0+	0.0-100.0	~5.0-100.0	0.0-30.0+
Expected Response	Decrease[8]	Decrease[8]	Decrease	Increase	Increase	Increase	Increase

[1]Based on a proportional count of 400 cells (800 valves)
[2]Base 2 [bits] (Weber 1973)
[3]Composite numeric expression of the pollution tolerances assigned by Lange-Bertalot (1979) to the common diatom species
[4]Sum of the percent abundances of all species in the genera *Navicula, Nitzschia* and *Surirella*
[5]Percent abundance of Achnanthidium minutissimum (synonym: *Achnanthes minutissima*)
[6]Percent abundance of the species with the largest number of cells in the proportional count
[7]Cells with an irregular outline or with abnormal ornamentation, or both
[8]Species richness and diversity may increase somewhat in mountain streams in response to slight to moderate increases in nutrients or sediment

Appendix D. Diatom association metrics used by the State of Montana to evaluate biological integrity in prairie streams: references, range of values, expected response to increasing impairment or natural stress, and criteria for rating levels of biological integrity. The lowest rating for any one metric is the rating for that site.

Biological Integrity/ Impairment or Stress/ Use Support	No. of Species Counted[1]	Diversity Index[2] (Shannon)	Pollution Index[3]	Siltation Index[4]	Disturbance Index[5]	% Dominant Species[6]	Similarity Index[7]
Excellent/None Full Support	>39	>3.99	>2.25	<50.0	<25.0	<25.0	>59.9
Good/Minor Full Support	30-39	3.00-3.99	1.76-2.25	50.0-69.9	25.0-49.9	25.0-49.9	40.0-59.9
Fair/Moderate Partial Support	20-29	2.00-2.99	1.25-1.75	70.0-89.9	50.0-74.9	50.0-74.9	20.0-39.9
Poor/Severe Nonsupport	<20	<2.00	<1.25	>89.9	>74.9	>74.9	<20.0
References	Bahls 1979 Bahls 1993	Bahls 1979	Bahls 1993	Bahls 1993	Barbour et al. 1999	Barbour et al. 1999	Whittaker 1952
Range of Values	0-100+	0.00-5.00+	1.00-3.00	0.0-90.0+	0.0-100.0	~5.0-100.0	0.0-100.0
Expected Response	Decrease	Decrease	Decrease	Increase	Increase	Increase	Decrease

[1]Based on a proportional count of 400 cells (800 valves)
[2]Base 2 [bits] (Weber 1973)
[3]Composite numeric expression of the pollution tolerances assigned by Lange-Bertalot (1979) to the common diatom species
[4]Sum of the percent abundances of all species in the genera *Navicula, Nitzschia,* and *Surirella*
[5]Percent abundance of *Achnanthidium minutissimum* (synonym: *Achnanthes minutissima*)
[6]Percent abundance of the species with the largest number of cells in the proportional count
[7]Percent Community Similarity (Whittaker 1952)